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A NOVEL CEMENT SLURRY DESIGN APPLICABLE TO HORIZONTAL WELL CONDITIONS

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Abstract

Horizontal wellbores raise many questions concerning the characteristics of cement. A successful horizontal cement job should prevent the formation of mud, water and gas channels. Free water channel forms on the upper side of the drain hole. Therefore, the following cement placement parameters should be studied to overcome the cementation problems: casing hole eccentricity, drilling fluid rheological behavior, hole geometry, spacer design (rheology), density, cement slurry design. This study focuses on cement slurry design in horizontal wells. Laboratory experiments are performed to get appropriate cement slurry design for horizontal wells. The cement slurry should have special properties and the purpose of this work is to achieve a formulation that has these properties. The slurry properties included zero free water, low fluid loss, high compressive strength, along with appropriate thickening time to allow for correct placement.

Laboratory tests are performed with different formulations and finally the best composition for cement slurry is achieved, that has zero free water and high compressive strength. This cement slurry is suitable for horizontal and deviated wellbores.

The results of these experiments are compared with two cement slurry formulation from two of Iranian oil fields. This comparison shows that our cement slurry characteristics are much better than two formulations from the field experiences.

Keywords: Horizontal well; cement slurry; rheology; free water.

1. Introduction

Horizontal drilling has many benefits, such as preventing water and gas coning, achieving inaccessible reservoirs, increasing production, etc. Acceptable production from horizontal well needs successful drilling and completion operation. There are four types of completion for horizontal wells: open hole, slotted liner, external casing packer, cemented and perforated liner. Hence, cementing of a horizontal well is an essential part of completion and it influences the future production from the well.

Designing proper cement slurry which is compatible with formation conditions is one of the most significant factors for a successful cement job. This thesis concentrates on laboratory tests that are performed in RIPI (research institute of petroleum industry) to get a cement slurry design suitable for deviated and horizontal wells.

Cement slurry properties must be controlled particularly in highly deviated and horizontal wells. Free water is the most important factor that should be as low as possible after cement sets. The other properties that are important are: yield point, plastic viscosity, fluid loss, gel strength, and the dynamic settling characteristics of cement slurry [1].

With regard to industry needs, cement slurry must be designed properly to fulfill the requirements of each well condition. To design a cement slurry formulation, several factors should be considered, including well depth, temperature, mud-column pressure, viscosity and water content of cement slurries, pumping, or thickening, time, compressive strength, quality of available mixing water, compatibility with drilling fluid and spacers, density, lost circulation and filtration control [2].

Experimental results that are performed in RIPI cementing laboratory are discussed to get the final formulation of cement slurry. The final formulation is compared with two formulations from one of Iranian oilfields and the results are shown.

2. Horizontal well cementing problems

Problems encountered during horizontal well cementing are similar to those on any cement job, but are aggravated by factors such as wellbore orientation, geometry, and gravitational forces. Directional deviation in the horizontal plane is not viewed as a significant problem to successful cementing other than where curvature may interfere with centralization or running of casing. Deviation in the vertical plane could contribute to centralization and drag problems as well as leaving high spots that may trap immobile mud in much the same manner as washouts. Wellbore geometry is affected by drill string contact on the low side of the hole which can lead to an oblong shaped wellbore and thus, incorrect hole volume calculations, unless adequate caliper logging is done. Gravitational forces affect centralization problems and progress solids settling from the wellbore fluids [1] .

Deposition of solids in the wellbore is one of the most severe problems in horizontal wells. Settling of barite or drill cuttings causes the mud on the low side of the annulus to have a higher density than the mud on the top side. The amount of solids, or channel size, appears to be a function of the rate of deposition and the rate of particle erosion by hydrodynamic forces. Even though smaller particles may remain in suspension, larger particles may not, and in horizontal systems they accumulate in the narrowest part of the annulus, which further diminishes the capability of the mud to remove them from the well [4]. Mud and settled drill solids which are not properly removed from the wellbore with the drill string can be a obstacle in getting casing to bottom in horizontal wells and these settled solids will be much more difficult to remove once casing is placed into the well. The best approach to minimize the settling problem is a properly designed mud system which is able to adequately transport solids and drill cuttings from the well.

Solid settling is not limited to the drilling mud, but also occurs in the cement slurries if proper precautions are not observed. Proper slurry design is of extreme importance, not only to prevent particle settling, but also to help cover appropriate rheologies for efficient placement and mud removal, as well as providing zero free water to help provide top-side integrity in the annulus. Cement slurries that have free water and/or settling tendencies can result in water channels on the top side of a horizontal annulus, or an area of reduced compressive strength cement which may not provide the annular seal required for zonal isolation during stimulation treatments. It is necessary that well-suspended, zero free water slurries be used in horizontal cementing applications.

Unstable slurries (those which exhibit tendencies to settle) caused considerable expense to the operators when cement solids were found inside the casing. Wiper plug failure was first blamed for this problem, but even more durable plugs failed to eliminate the solids.

Improperly designed spacer systems and cement slurries can cause cement job failures in perfectly planned and executed jobs. Spacer systems must be compatible with the drilling fluid in order to prevent forming a highly viscous interface which may promote mud channeling, must have flow properties conducive to the removal and suspension of settled solids, and be stable for extended periods of time at wellbore temperatures.

3. Slurry design

The first concern in designing cement systems for oil and gas wells is to ensure that the slurries are suitable for field applications. This means that they can easily be mixed and pumped with conventional surface equipment, and placed at the required depth with proper thickening time. The slurry must also remain stable during the whole process. For this purpose, an optimization is carried out for each system. Therefore, Proper slurry design is critical to the success of a cementing job. While some deficiencies may be tolerable in vertical wells, horizontal wells are not forgiving and the highest quality slurry must be used. Essential parameters include zero free water at formation temperature and minimal settling.

Free fluid may show up not as clear water, but as a thin portion of cement-colored fluid containing well dispersed cement fines. This type of slurry should be rejected or adjusted to eliminate this phenomenon because the less dense portion at the top may not provide the strength required for a proper seal, and may provide a path for well fluid movement. This could also leave the casing exposed to corrosion from down hole water contact.

Slurry stability must also be considered an integral part of the design and various procedures have been devised to examine slurry settling characteristics. To prevent settling, cement yield point should exceed 15 lb/100 ft^2 [2] .

Cementing long horizontal intervals often requires a cement slurry with a low yield point to reduce friction pressure while pumping, in an effort to avoid exceeding the equivalent circulation density of the well. Additives are available to aid in designing slurries in this manner. Caution should be used when designing thin slurries to protect against settling or free water [2].

Proper attention must also be given to standard testing such as thickening time, compressive strengths, and fluid loss. It is not uncommon for fluid loss values of less than 30 ml/30 minutes to be used [2]. Numerous gas migration control additives are now available and should be incorporated into the slurry design as needed.

3.1 Cement additives

Cement additives have played an important role in the advancement of cementing technology. To properly use the available cements, additives were developed to control the major cement properties, i.e., thickening time, consistency, fluid-loss rate, free water, setting time, etc. Consequently, a wide variety of cement additives is now available to alter cement properties to meet most well conditions. For example, calcium lignosulfonates and other retarders maintain the cement in a slurry form to allow long pumping times for great depths and at high bottomhole temperatures [3].

Recent developed slurry additives have extended design capabilities considerably. Fluid loss additives are now available for any degree of salinity desired and for any wide temperature ranges. Fume silica or special heavyweight materials have proven beneficial in providing slurry stability for horizontal applications. It is now possible to design heavy weight slurries with reasonable flow properties and still maintain the weighting material in suspension. Fume silica and improved surfactants have increased the design capabilities for low density and/or foamed cement slurries where these have application. Non-lignin, non-cellulose retarder chemicals have been developed to provide more predictable slurry response and improved control over thickening time.

Proper slurry design often requires extensive laboratory examination of the various parameters to arrive at the desired results. In some cases, it may be extremely difficult or impossible to meet all the slurry properties that would be considered ideal. It is very important that the maximum possible lead time is provided before any particular job so that slurries can be optimized.

4. Results and discussion

Laboratory experiments are performed to obtain appropriate cement slurry properties. These properties are important to get a cement slurry that is suitable for horizontal and deviated wells. Some of these properties are as follows:

- free water
- cement rheology
- thickening time
- ultimate compressive strength

The accurate and reliable characterization of cement slurries still presents a problem for the industry. These fluids exhibit a fairly complex rheological behavior which depends not only on fluid composition and on the mixing procedure, but also on shear history, temperature, and on the particular testing procedures used [3] .

For all these tests cement slurries behaviour assumed as Bingham plastic model and all the rheological calculations are made from a linear relationship between shear stress and shear rate. This relationship called "apparent viscosity (AV)".

Table 1 shows the shear stress differences by reducing the amount of retarder (D-13) and friction reducer (FR-2). It is clear that since the shear stress values are higher in test 2, therefore; cement slurry viscosity of test 2 is less than test 1.

Table 1- Comparison between test 1 and test 2

Composition	amount (test1)	amount (test 2)	ɵ(rpm)	shear stress (test 1)	shear stress (test 2)
Cement	1000 g	1000 g	600	120	92
Water	300 cc	300 cc	300	70	49
Sacalite	100 cc	100 cc	200	51	34
D-13	6 g	4 g	100	30	18
FR-2	4 g	4 g	6	7	2
Antifoam	2 cc	2 cc	3	3.5	1.5

Table 2- Comparison between test 3 and test 4

Composition	amount (test 3)	amount (test 4)	ɵ(rpm)	shear stress (test 3)	shear stress (test 4)
Cement	1000 g	1000 g	600	112	67
Water	350 cc	350 cc	300	70	37
Sacalite	100 cc	100 cc	200	55	27
D-13	2 g	3 g	100	41	18
FL-19	2 g	4 g	6	21	12
Antifoam	2 cc	2 cc	3	18	10

The results from ultrasonic cement analyzer (UCA) are shown in figure 1. The ultrasonic cement analyzer continuously monitors the strength development of test 4 cementing composition. Measurements of the cement's ultrasonic velocity are started during the fluid state and continued through initial set to 3:57 hours under down hole simulated pressure and temperature. Strength values are continuously computed and displayed until it reaches to 500 psi strength after 4:04 hours, which is shown at the top right of figure 1. Besides, strength 2 shows the accuracy of device that can measure till 19999 psi of strength. After 96:09 hours working and analyzing the strength of set cement was 3599 psi and the point is that such strength value for cement is perfect, because it should be more than 2000 psi to overcome stresses and collapse pressures of the formation that is applied to cement bond during the life of a well.

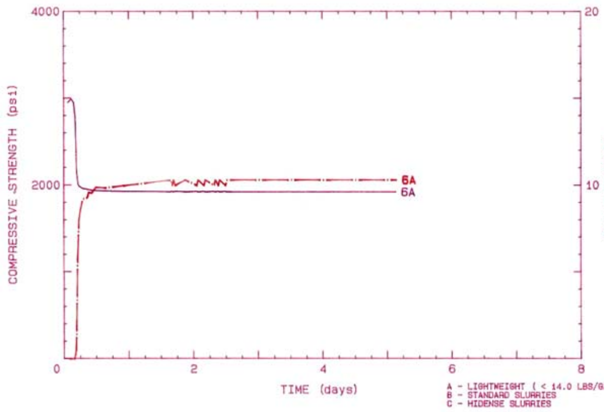

Fig. 1 Compressive Strength curve of final formulation

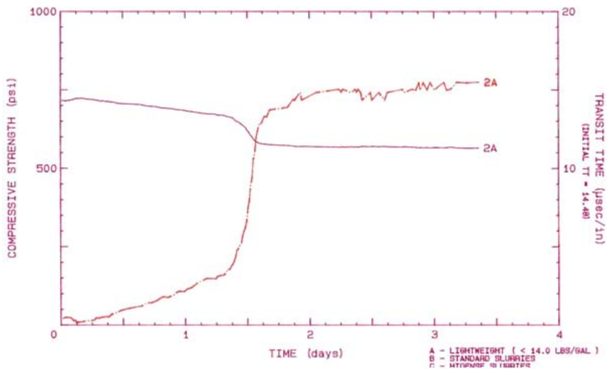

Fig. 2 Compressive Strength curve of oil field A

For optimization of cement slurry formulation, more additives are added to the cement slurry. For reducing weight of cement D-124 is added to the cement slurry, because for horizontal wells, most of the time of cementing is in reservoir layer and if the cement be too heavy it will penetrate through porous media and loss circulation will occur.

Sometimes there is a risk of gas migration; therefore, gas migration preventers should be added to the slurry. Note that all the additives that are using together should be compatible with each other otherwise, cement slurry become so viscous and it will not be pumpable. The retarder that is used here is R-8 that increases thickening time of cement.

Avoiding of settling of set cement in the casing an anti-settling additive which is called D-153 will be added to slurry. To control fluid loss D-167 is used.

Rheological properties of cement slurry are measured with viscometer and viscometer reading is shown in table 3.

Table 3- Viscometer reading for final test

θ(rpm)	Shear rate	shear stress
600	1022	235
300	511	131
200	341	91
100	170	50
6	10	7
3	5	3

Table 4-Comparison of compressive strength of different cement compositions

formulation / Strength	Oilfield A(90 pcf)	Oilfield B(120 pcf)	Final Composition
Initial set (50 psi)	13:01 hr	9:12 hr	4:08 hr
Strength 1 (500 psi)	37:00 hr	10:07 hr	4:32 hr
Current strength	773 psi @ 80:37 hr	1885 psi @ 82:24	2063 psi @ 123:34hr

UCA measurements of the cement slurry of the final formulation is shown in figure 6.6 and it shows initial set to 4: 08 hours under downhole simulated pressure and temperature. Strength values are continuously computed and displayed until it reaches to 500 psi strength after 4:32 hours, which is shown at the top right of figure 6.6 that is written strength 1. After 123:34 hours working and analyzing the strength of set cement is 2063 psi.

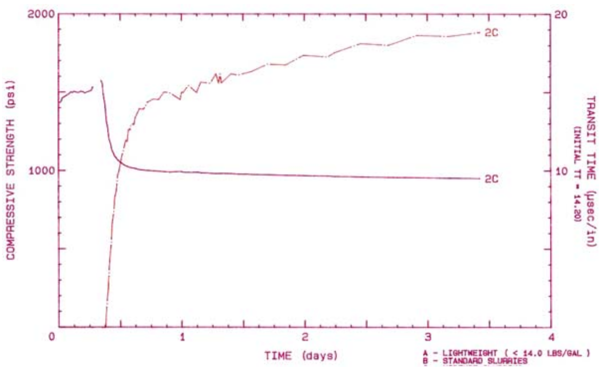

Fig.3 Compressive strength curve of oil field B

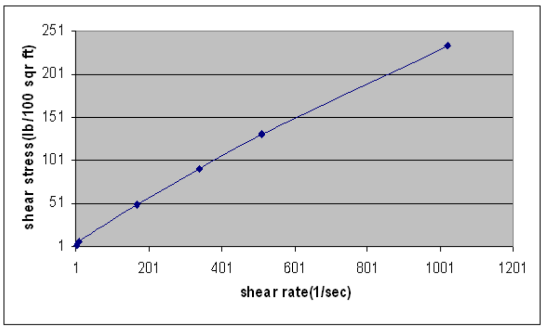

Fig.4 Flow behaviour of the optimized formulation

Compressive strength curves of two cement slurry formulations from two Iranian oil fields are shown in figure 3 and figure 4. The comparison between our cement formulation and these two formulations is shown in table 6. This table shows that the composition which is achieved in this work is much better than those two compositions because, the time to reach initial set is lower than the others. Furthermore, wait on cement time is also lower, therefore, drilling can start earlier and it is more economic and cost effective.

One feature of this study is establishment of the ability to reduce or to control solids settling from drilling fluids by maintaining at least a minimum threshold yield point value. Controlling the mud yield point and settling will help eliminate mud channeling along the low side of the annulus.

Table 5 Comparison of cement slurry compositions

Optimized cement slurry formulation		Oilfield cement slurry formulation	
Composition	Amount	Composition	Amount
Cement(G Kerman)	1000 g	Cement(G Kerman)	1000 g
Water(field)	1500 cc	Water(field)	450 cc
D-124	1500 g	D-124	220 g
Sakalite	300 cc	--------	--------
Microblock	300 cc	--------	--------
D-600	100 cc	D-600	130 cc
R-8	25 g	--------	--------
D-153	8 g	--------	--------
D-167	10 g	--------	--------
CFR-2	10 g	CFR-2	8 g
--------	--------	D-112	6 g
Anti foam	10 cc	Anti foam	10 cc

Table 6-Comparison of cement slurry properties

Cement slurry properties	Optimized cement slurry formulation	Oilfield cement slurry formulation
Density	90 pcf (12 ppg)	90 pcf (12 ppg)
Apparent viscosity	117.5 cp	121 cp
Plastic viscosity	121.5 cp	219 cp
Yield point	9.5 Ib/100sq.ft	24 Ib/100sq.ft
Fluid loss	14 cc	120 cc
Thickening Time(30 Bc)	150 min	150 min
Thickening Time(70 Bc)	180 min	210 min
Free Water	0 %	Free Water= 10 %

Vertical well displacement studies demonstrates that a high yield point mud would reduce mud displacement efficiency by reducing fluid mobility and that mud displacement efficiency is greatest when pumping rates are maximized, regardless of the rheological properties of the cement. In deviated wells, pumping rates are a secondary consideration to the condition of the drilling mud. Turbulent flow rates might help remove a channel of settled solids; however, the tests that used thin preflushes, which were pumped in turbulent flow, indicated only a marginal improvement.

Casing centralization, which is known as a major factor in vertical displacement studies, is more important in deviated holes because the loads acting on the casing tend to force it to the low side of the wellbore.

Solids settling from the drilling fluid and free water breakout from the cement slurry can potentially have significant undesirable effects on cementing deviated wells.

5. Conclusions

1. Settling of solids from drilling mud to the low side of the annulus creates a continuous channel of uncemented material. Formation of such a mud channel results in an incomplete cement sheath, leaving a possible channel for the migration of well fluids.
2. In high-angle wells, solids settling from the drilling fluid to the low side of the hole can cause serious drilling and completion problems.
3. Laboratory tests with weighted water-based drilling fluids demonstrate that coherent mud channels formed by solids settling can remain at the bottom of the annulus of a deviated wellbore following mud displacement by cement.
4. Tests also indicate that excess water in the cement can result in a water channel at the top of the cemented annulus in a highly deviated well.

6. Recommendations

The cement slurries should be designed to contain no more than a trace of free water higher than 0% (highly recommended). The testing procedure for free water measurement should be altered from the standard format. The most realistic evaluation can be made by preconditioning the slurry to BHCT before placing it into the test cylinder deviated to at least a 45° angle. This property will affect the overall productive capability of the well because of the isolation needed for maximum effectiveness of localized fracturing and stimulation procedures.

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Nomenclature

ECP	External casing packer
TT	Thickening time (hr/ min)
CS	Compressive strength (psi)
GS	Gel strength (Pa)
PV	Plastic viscosity (cp)
YP	Yieldpoint (lb/ 100 sq. ft)

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