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Study on Cement Slurry System for Deep and Ultra-Deep Wells

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Abstract
Cementing quality can't meet the requirements in deep and ultra-deep wells cementing because of many factors such as long open hole section, multiple pressure system, high temperature and high pressure. In order to solve the problem of cementing in deep and ultra-deep wells, retarder and fluid loss additive were studied, then the cement slurry system for deep and ultra-deep wells were developed and the performance was evaluated. The results show that the cement slurry has steady performance for high temperature, adjustable thickening time, less fluid loss, good settlement stability, and high compressive strength, all of which can meet the requirement of cementing in deep and ultra-deep wells. Pilot tests of this cement system were conducted in more than 30 wells in Shengli, Dagang, Liaohe, Jiangsu, Jilin and Offshore oilfield, cementing qualities of these wells were qualified, which indicates that comprehensive performance of this kind of cement slurry system can meet the technical requirements for deep and ultra-deep wells cementing, which provides the references for the deep and ultra-deep wells cementing in all of the word.

Key words: Deep and ultra-deep wells; Cementing; Fluid loss additive; Retarder; Thickening time

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INTRODUCTION
With the development of drilling technology and continuous exploration of oil and gas, the well depth is increasing, several problems are encountered in deep and ultra-deep wells cementing process because of high temperature and high pressure, which are mainly reflected as: (a) fluid loss is high and thickening time is difficult to control under high temperature; (b) the common cement slurry can not satisfy the cementing need under high temperature and high pressure, its performance is not up to the requirements of design; (c) the reliability of cementing tool is reduced under high temperature and high pressure. Therefore, in order to enhance the cementing quality, the higher requirements of cement slurry and cementing tools are put forward in deep and ultra-deep wells than that of conventional well, at the same time, to meet the general cementing requirements, cement slurry system should also consider the performance effect under high temperature, narrow annulus, long open section cementing, the strength development of top cementing stone and other factors. In this paper, some cement slurry additives for deep and ultra-deep wells were studied and the new cement slurry was development.

1. CEMENT SLURRY ADDITIVES FOR DEEP AND ULTRA-DEEP WELLS

1.1 Retarder
The function of a cement retarder is to effectively increase the time the cement slurry remains fluid and pumpable. When mixed at the recommended water to cement ratio, an unretarded slurry containing API Class H or G cement may be safely placed at a depth of 2500 m where the bottom hole circulating temperature is less than about 50 ℃. However, at depths and temperatures in excess of these limits, it is necessary to add chemicals to prevent the slurry from setting prematurely. These additives are

especially important in deep wells where circulating temperatures can exceed 200 ℃.

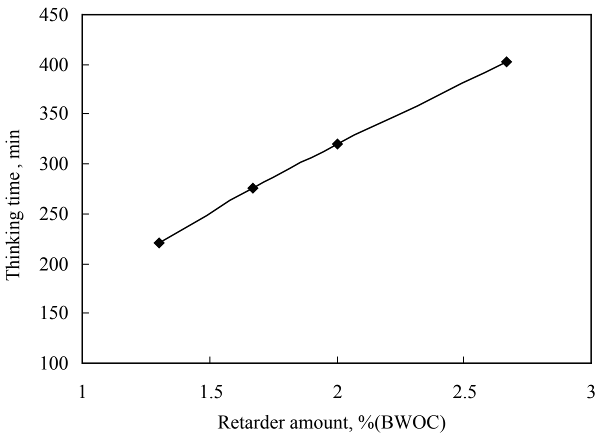

Figure 1
The Relation Between Retarder Amount and Thickening Time

A high temperature tolerant cementing retarder HTR-2 was developed through numerous experiments, which is an organic polymer compound, having high solubility in water. The relation between retarder amount and thickening time is showed as Figure 1. As seen from the Figure 1, HTR-2 retarder possesses strong retarding extend with an increase in the thickening time, at the same time, the slurry can be adjusted freely in a wide temperature range to satisfy the cementing requirement. HTR-2 retarder also has a dilution effect, thus it can reduce the consistency of the slurry by replacing part of the dispersant in the formulation.

HTR-2 retarder can delay the normal setting time at high temperature, but the compressive strength would not be affected during the cementation process. The compressive strength is shown in Table 1.As is shown from the Table 1, in different amount and temperature conditions, HTR-2 almost does not affect the compressive strength of cementing. The cement stone strength decreased with time increased slightly, but does not affect the actual application. As the HTR-2 has a very small effect on water and cement ratio, the cement slurry viscosity and dynamic shear force are not affected, thus the strength of cement stone is not affected, the retarder HTR-2 can meet the requirements of site operation.

Table 1
Compressive Strength of Cement Paste

No.	HTR-2 amount/%	Test temperature/℃	Time/h	Compressive strength/MPa
1	2.2	120	168	20.2
2	2.4	130	48	21.8
3	2.4	135	120	16.8
4	3.5	150	24	22.8
5	3.5	150	48	22.2

1.2 Fluid Loss Additive

For more than 20 years, fluid loss control agents have been added to oil-well cement slurries and it is now recognized in the industry that the quality of cementing jobs has significantly improved. As cement is pumped across a permeable rock surface under pressure, cement filtrate or water is lost or squeezed out of the cement into the rock. Indeed, it is generally clearly acknowledged that a lack of fluid loss control may be responsible for primary cementing failures, due to excessive density increase or annulus bridging and that formation invasion by cement filtrate may be deleterious to the production. Cement-fluid loss must be controlled to obtain the right rheological properties for placing the cement and to ensure a good cement bond to pipe and formation.

The new cementing fluid loss additive HFLA-1 for deep and ultra-deep wells is developed by China university of petroleum, which is a kind of polyolefin based polymer compound when mixed with auxiliary materials such as slag, it can withstand temperature up to 200 ℃. Change the amount of fluid loss additive at 90 ℃, fluid loss of cement slurry was measured, the results are showed in Figure 2.

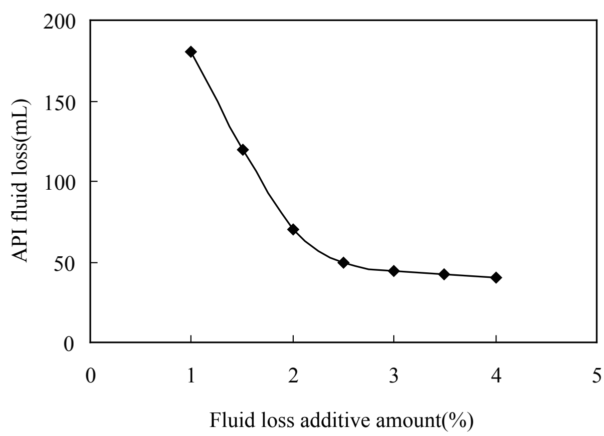

Figure 2
The Relation Between Fluid Loss and the Amount of Fluid Loss Additive

As is shown in Figure 2, fluid loss is reduced with the increase of agent amount. When fluid loss additive is lower than 2%, the cement slurry fluid loss is more sensitive to the amount; when the adding amount is more than 3%, the amount of cement slurry fluid loss additive has a small effect on fluid loss, fluid loss can be controlled at a low level; when the amount of fluid loss additive reaches 2%, cement slurry API fluid loss can be control below100 mL, when the amount of fluid loss additive reaches 3%, cement slurry API fluid loss can be controlled below 50 mL.

It was found that the fluid loss additive HFLA-1 does not have any impact on slurry thickening time, compressive strength as well as other performance (Table 2). This also indicates that the fluid loss additive HFLA-1 has good compatibility with retarder, it can facilitate cement slurry formulation design for deep and ultra-deep wells.

Table 2
Influence on the Cement Slurry Thickening Time and Compressive Strength of HFLA-1

No.	BHCT, ℃	The cement slurry composition (weight ratio)					Thickening time, min	24h Compressive strength, MPa
		Cement	Silica fume	HFLA-1	HTR-2	Freshwater		
1	135	100	35	2.5	0.7	56.5	352	21.5
2	135	100	35	5.5	0.7	56.5	368	22.2
3	150	100	35	5.6	0.95	56	332	23.3
4	150	100	35	5.85	0.95	56	326	24.2

2. COMPREHENSIVE PERFORMANCE AND FORMULATION OF SLURRY FOR DEEP AND ULTRA-DEEP WELLS

For deep and ultra-deep wells, the cement slurry is fundamentally based on oil well cement, the overall performance is the role of the sum of its individual components when mixed with massive additives. Each well site must be endorsed with the specific requirements by the cement slurry formulation. The research scope is to overcome the existing problems with the application of developed additives, the cement slurry formulation is designed.

To get a better high strength and low density cementation system, numerous of experiments were carried out, optimizing dispersing agent, filtrate reducer, retarder, changing the silicon particle, hollow microsphere, and changing the dosage, then get a different formula, as following:

Formula A：G Grade Jiahua cement, 20% of drift beads, 35% of silicon particle,5.5% of filtrate reducer(HFLA-1), 2.5% of dispersing agent(langdy-906L), 1.2 % of retarder(HTR-2), and 0.2% of defoamer(langdy-19L).

Formula B：G Grade Jiahua cement, 25% of drift beads, 35% of silicon particle,6.5% of filtrate reducer(HFLA-1), 2.5% of dispersing agent(langdy-906L), 0.8% of retarder(HTR-2), and 0.2% of defoamer(langdy-19L).

Formula C：G Grade Jiahua cement, 30% of drift beads, 30% of silicon particle, 6.5% of filtrate reducer(HFLA-1), 2.5% of dispersing agent(langdy-906L), 1.2% of retarder(HTR-2), and 0.2% of defoamer(langdy-19L).

Table 3
Water Slurry Formulation Performance

No.	Density, g/cm^3	Thickening time, min	Pumping time, min	48h Compressive strength, MPa		Loss of water, ml	Fluidity, cm	Free liquid, ml	Rheology 300/200/100/6/3
				BHST	BHCT				
A	1.60	444	439	25.2	23.2	20	22.5	0.3	72/50/28/5/4
B	1.50	359	358	23.6	22.4	22	22.5	0.2	86/57/28/3/1.5
C	1.40	400	390	21.5	21	12	24.0	0.2	86/57/28/3/1.5

Micro-beads which possesses water-adsorbent properties when added directly into the cement slurry, increases the solid content in the system and affect its mobility. HTR-2 retarder has a dilution effect but still difficult to ensure a good mobility, but when langdy-906L dispersant added, the experiment shows significant improvement in the rheology of the cement slurry. From the Table 3, we can get that system has a fine performance in a whole. In the experimental temperature range, different density of cement has a similar thickening time, which makes the adjustment of formula more convenient and after 48 h time, the strength will get over 20 MPa, and API hydro loss will be under 30 ml.

2.1 Cement Slurry Stability

Cement slurry for deep and ultra-deep wells cementing must not only ensure thickening time given, fluid loss, rheology and compressive strength, but also have good sedimentation stability, because the formation can not be well separated with poor sedimentation stability of cementing slurry, especially in horizontal and deviated wells. Sedimentation instability phenomenon often occurs in low-density cement slurry and Ultra-high density cement slurry, because in these system the density difference between the additives, the weighting materials with cement, It can easily lead to the particle sedimentation. Evaluation of sedimentary stability is mainly measured through API free liquid and BP methods, BP method is adopted in this paper, so the cement slurry is prepared in accordance with this formulation and the differential density of the cement slurry was measured accordingly. The experiment results are shown in Table 4.

Table 4
Settling Stability Comparative Experiments

No.	Cement, %	Silica fume, %	Drift beads, %	Freshwater, %	HFLA-1, %	langdy-906L, %	HTR-2, %	langdy-19L, %	Mobility, cm	Upper and lower density difference g/cm^3
A1	100	29.8	19.15	72.5			1.25	0.05	18.5	0.11
A2	100	29.8	19.15	72.5	5.85	1.06	1.25	0.05	22.5	0.03

Experiment data shows that langdy-906L and HTR-2 can significantly improve the slurry mobility and reduce the water requirement for the slurry preparation, moreover, HFLA-1 is a hydrophilic polymer compounds with strong adsorption capacity, which can enhance slurry suspension ability by absorbing and enwrapping drift beads, barite and cement, thus sedimentation stability can be improved greatly in contrast.

2.2 Slurry System Adaptability

Oil and gas resources are not concentrated in China, there are great differences in cement grade and salinity of the oilfield water, cementing process may exhibit differences for deep and ultra-deep wells in different oilfield. To meet the different oilfield requirement, the adaptability test of the cement slurry was performed using water from Xinjiang, Dagong and Liaohe Oilfield. It was found that the performance of the cement and water quality in the slurry of the same formulation have certain difference, especially the cement quality and water salinity. This is mainly because of different C_3A content and effect on polymer additives by mineralization ion. Fortunately, in the research and development of the additives, this shortcoming has been considered by adding some additional components to balance these negative effects. Therefore, the cementing requirement can be met by proper adjustment of the amount of the additive in the same area. The results are shown in the Table 3.

Table 5
Adaptability Test for the Cement Slurry System

Temperature BHCT ℃	The cement slurry composition (weight ratio)							Cement slurry performance	
	Cement	Beads	Silica fume	HFLA-1	HTR-2	Water		API fluid loss ml	Thickening time min
130	Ak100	--	35	4.3	0.5	Fresh water	58	32	355
130	Ak100	--	35	4.3	0.5	High mineralization water	58		76
130	Ak100	--	35	5.0	0.75	High mineralization water	58	27	320
140	JH100	18	32	7.2	1.7	Dagang	80	25	250
130	AK100	–	35	5.0	0.75	Xinjiang	58	28	335

Note: AK is Xinjiang G-class cement, JH Jiahua G class cement, High mineralization water (mineral content is 30000 ppm).

3. FIELD APPLICATION

The Cement slurry System has been used in Shengli, Dagang, Liaohe, Jiangsu, Jilin and Offshore oilfield etc to cement over 30 wells for side-tracked well, deep gas well, etc.. It has effectively prevented gas migration with high qualified cementing.

3.1 Changshen 103 well

Changshen 103 well is a deep natural gas exploratory well located in the south part of Songliao basin in Jilin oilfield. The designed well depth is 4150m with lost zone and long column, and the BHCT is 93℃ To guarantee good cementing, the stage collar is set in intermediate casing at 2100m and stage cementing technology is adopted. Dual thickening and dual density cement slurry are used in the first stage cementing, where Cement slurry System (density of 1.40g/cm^3) is used as lead slurry up to the stage collar to decrease the column hydrostatic pressure in long interval annulus and prevent migration. The slurry compositions are the following.

Lead slurry: Jiahua class G cement + 46.7% enhancing agent PZW + 41.6% microsphere + 10% latex additive BCT-800L + 4% fluid loss control additive HFLA-1 + 1% dispersant CF40S + 1% defoamer D50 + 0.4% retarder HTR-2 + 1% defoamer G603 + 86%water

Tail slurry: Jiahua class G cement + 35% silicon powder + 2% microsilicon + 8% latex additive BCT-800L + 3.5% fluid loss control additive HFLA-1 + 0.8% dispersant CF40S + 0.6% defoamer D50 + 1% retarder BXR-200L + 0.6% defoamer G603 + 47.5% water

The operation was performed smoothly and high qualified cementing was obtained.

3.2 Changshen 5 Well

Changshen 5 well, located in Jilin Changling rift, is a deep natural gas exploratory well with designed depth 5400 m. In production casing cementing, double stage cementing technology is employed, and the stage collar set in intermediate casing at 2850 m. A washing fluid with a density of 1.0-1.03 g/cm^3 and flushing efficiency of more than 90% is adopted in both stage cementing. Then pump viscous spacer with a density of 1.0-1.07 g/cm^3, and keep washing fluid and spacer height in annular respectively about 200-300 m.

A high strength low density Cement slurry System with a density of 1.40 g/cm^3 as lead slurry filling up in the annulus about 1043 m, and a normal density Cement slurry System with a density of 1.88 g/cm^3 as tail slurry filling up in the annulus about 1000 m, are employed in the first stage of cementing. As a result the bottom density is about 1.49 g/cm^3, so a loss can be avoided.

In the second stage cementing, a high strength low density slurry with a density of 1.45 g/cm^3 is employed, which is designed to fill up to the surface, i.e. the interval isolation about 2850 m.

The slurry composition is as following.

The first stage lead slurry: Jiahua class G cement + 20% silicon powder + 43% microsphere + 50% enhancing agent PZW + 9% Suspension BCS-020S + 4% latex additive BCT-800L + 10% fluid loss control additive HFLA-1 + 0.4% defoamer D50 + 2.2% retarder BXR-300L + 2.64% retarder BXR-300L EX + 0.4% defoamer G603 + 106%water

The first stage tail slurry: Jiahua class G cement + 35% silicon powder + 4.25% Suspension BCS-020S + 3% latex additive BCT-800L + 6% fluid loss control additive HFLA-1 + 0.4% defoamer D50 + 1.1% retarder BXR-300L + 1.32% retarder BXR-300L EX + 0.4% defoamer G603 + 46%water

The well log shows the qualified rate for a whole well is 98.84%, and the high qualified rate of 93.49%. For the first stage cementing the qualified rate is 100% and the high qualified rate of 96.46%.

CONCLUSION

a. There are several constraints in designing conventional high-density cement systems for Deep and Ultra-deep Wells. Cement slurries that are required in such wells need to have low rheology, stability, high early compressive strength, etc.

b. Matched with other additives the slurry system in this paper has low fluid loss, anti-migration and good rheological properties to meet the needs of various cementing.

c. Drilling and cementing solutions presented in this paper should help in long cement column cementing, providing reference for deep and ultra-deep wells.

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