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Development and Application of High Thermostable Elasto-Toughness Latex Cement Slurry System for Ultra-deep Gas Wells

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Abstract: To solve the challenges in the cementing of ultra-deep high-temperature and high-pressure (HTHP) gas wells, a latex cement slurry system with good high thermostable anti-gas channeling and elasto-toughness performances was developed, which uses the styrene-butadiene latex DC200 to enhance the anti-channeling performance of cement slurry and reduce the permeability of set cement, and additionally use modified elastic particles, organic polymer fibers and inorganic mineral fibers as composite toughening materials to enhance the elasto-toughness of set cement effectively. The evaluation results show that the temperature resistance of this system is above 160°C, the SPN value is <1, and the static gelling strength transition time is only 12 min, indicating a good anti-channeling performance. Compared with the conventional set cement, the permeability was reduced by about 80%, the elastic modulus was reduced by about 60%, the bending strength was increased by about 84%, and the impact resistance of set cement was increased by about 86.69%, showing excellent mechanical properties. This system has been successively applied in well SHN-401 and well SHN-4-1 in Tazhong Oilfield, and the overall cementing quality was good. It proves that this cement slurry system can meet the cementing technical requirements for ultra-deep HTHP gas wells, and has good application prospect.

Keywords: Gas Well, Cementing, Anti-gas Channeling, Elasto-Toughness Latex, Cement Slurry

1. Introduction

As the oil and gas exploration & development proceeds forward in Tarim Basin, China [1-2], all wells drilled in blocks Shunnan and Shunbei [3-4] exceeded 7,000 m, and geological conditions became more complicated [5-6], resulting in more difficulties in well construction. What challenges most is the anti-channeling in the cementing of ultra-deep high temperature and high pressure wells [7-9].

The following challenges have to be addressed in the cementing of deep gas wells: (1) The temperature of target layer is up to 160°C, which requires high thermostable performance of cement slurry chemicals; (2) high gas layer pressure and high oil/gas migration velocity render high requirements on the anti-channeling performance of cement slurry; (3) During the operation and production in late stage, the temperature and pressure changes in the wellbore may damage the cement ring and cause micro-crack, which has high requirements on the elasto-toughness of set cement. Hence, a cement slurry system with excellent high thermostable anti-channeling performance and mechanical properties was developed for the cementing of ultra high-temperature and high-pressure gas wells.

In view of the above problems, one high thermostable elasto-toughness latex cement slurry system has been developed using selected anti-gas channeling agent, elastic particles and toughening material; the mechanical properties of elastic toughness set stone have been analyzed and evaluated with bending resistance, impact resistance and triaxial stress test, so that its applicability in high temperature and high pressure gas wells cementing can be guaranteed. This cement slurry system has been piloted on field for 2 well times, with high cementing quality and effective sealing of gas layers being achieved.

The research results have reference significance for ultra-deep gas wells cementing, which can effectively promote the safe and efficient long-term development of deep gas reservoirs in China.

2. Optimization of Anti-gas Channeling and Elasto-toughness Materials

2.1. Optimization of High Thermostable Anti-gas Channeling Agent

As an elastic particle smaller than the cement particles, the latex particle can be uniformly dispersed in cement slurry, enter into the gap of cement particles, reduce the fluid loss of cement slurry and the permeability of set cement, and prevent gas intrusion and migration in set cement effectively; it can also be agglomerated among the cement particles to form a non-permeable membrane covering the surface of filter cake under the pressure difference, which balances the formation pore pressure and prevents gas intrusion effectively. Additionally, it also involves in the formation of CSH gel network, and bonds each other to form an elastic network body [10] in the entire cement matrix structure, which can avoid the stress concentration and reduce the brittleness of set cement. The styrene-butadiene latex DC200 was selected through laboratory experiment, with a particle size of 200 to 500 nm, temperature resistance of 200°C and optimal dosage of 8~15%.

2.2. Optimization of Elastic Particles

According to the filling theory, when the set cement is subjected to an external force, the elastic particles with low elastic modulus will be filled into the space among CSH gels, and form a soft support between the cement hydration product and the particle surface, so that the set cement can be deformed to a certain degree without breakdown. Therefore, it satisfies the elasticity requirements of set cement [11]. Through applying technologies such as pulverization, swelling and coating on ordinary elastic particles in laboratory experiment, a modified elastic material SFP1-2 [12] was formed, which has the particle size distribution of 10μm~100μm, the elastic modulus of 6%-11% of the conventional set cement, and the volume fraction of 2.3%-8.0% under non-compressive conditions. The effects of different SFP1-2 dosages on the elastic modulus, bending strength and compressive strength of set cement were evaluated. The results are shown in Table 1.

Table 1. *Effects of SFP1-2 on set cement mechanical properties.*

SFP1-2 dosage, %	Compressive strength, MPa		Bending strength, MPa		Elastic modulus, GPa
	24 h	48 h	24 h	48 h	48 h
0	25.2	28.2	4.25	4.56	14.5
3	17.9	22.4	4.46	4.70	10.1
5	16.2	19.3	4.38	4.82	8.9
6	13.5	15.1	4.70	4.60	7.8
7	9.5	9.8	3.1	3.1	6.1
8	2.1	3.3	1.2	1.2	4.9

The results suggest that, the compressive strength is decreased along with the increase of SFP1-2 dosage. When the dosage is less than 6%, the compressive strength is sufficient enough to meet the field application; when the dosage exceeds 6%, the compressive strength will be too low to be used. As the dosage of SFP1-2 increases, the bending strength increases first and then decreases; once the dosage exceeds 6%, the bending strength is too low. The elastic modulus of set cement decreases significantly with the increase of SFP1-2 dosage, which improves the brittleness of set cement effectively. Through indoor evaluation and considering the mechanical properties of set cement comprehensively, the optimal dosage of SFP1-2 is defined as 3%-6%.

2.3. Optimization of Elasticizer

As the key element to improve the tensile strength and toughness of set cement, elasticizer shall have the following characteristics: first, it can effectively improve the toughness and ductility of set cement; when set cement is subjected to thermal strain or impact, it can effectively control the extension and expansion of crack to ensure the integrity of set cement under the external load and improve its impact resistance; second, the elasticizer can be freely dispersed in cement slurry, rather than being agglomerated, and it has little influence on the conventional performance of cement slurry. Based on the above principles, several elasticizers have been evaluated and optimized, and the experimental results are shown in Table 2.

Table 2. *Elasticizer optimization and evaluation.*

Material number	Dosage, %	Tensile strength, MPa	Dosage, %	Tensile strength, MPa	Dosage, %	Tensile strength, MPa
SFP2-1	0.1	2.7	0.2	4.2	0.25	4.5
SFP2-2	1	3.8	2	4.3	3	4.4
SFP2-3	1	2.1	5	2.3	10	2.5
SFP2-4	3	2.2	8	2.6	15	2.8

Note: SFP2-1 is organic polymer fiber, SFP2-2 is inorganic mineral fiber, SFP2-3 is whisker, and SFP2-4 is polyester fiber.

SFP2-1 and SFP2-2 exhibit obvious toughening effects. SFP2-1 is a kind of organic polymer high-strength chopped fiber with chemical resistance and good mechanical properties: low elastic modulus (3.8 GPa), high tensile strength (≥270 MPa), and etc. However, once the dosage of SFP2-1 is higher than 0.2%, the thickening of cement slurry is obvious, so the dosage should be controlled between 0.1%-0.2%. Whereas, SFP2-2 is a kind of high-performance inorganic mineral fiber [13], which is made of single-component mineral raw materials, and it is a non-synthetic amorphous material with pure natural property, high tensile strength, low elastic modulus and high-temperature resistance, which can be applied in 600°C or higher temperature. The experimental results suggest that once the dosage of SFP2-2 is higher than 2%, the tensile strength of set cement increases insignificantly, so the optimal dosage of SFP2-2 was defined as 1-2%.

3. Composition and Performance Evaluation of Elasto-toughness Anti-gas Channeling Cement Slurry System

By selecting styrene-butadiene latex DC200 as the high thermostable and high-efficiency anti-gas channeling agent, selecting SFP1-2, SFP2-1 and SFP2-2 as the composite brittleness reducing and toughening materials, and optimizing the associated additives, a set of elasto-toughness anti-gas channeling cement slurry system has been developed and evaluated. The basic formula of this system is as follows:

Grade G cement + SiO_2+ dispersant + fluid loss reducer + retarder +10-15%DC200+ stabilizer + defoamer + 3-6% SFP1-2 + 0.1-0.2% SFP2-1 + 1-2% SFP2 -2 + 44% water (water to solid ratio).

Table 3. *Cement slurry system general performance.*

Density, g/cm^3	n	K $Pa\cdot s^n$	API fluid loss (30min)		Free liquid, mL	Thickening time (transition time), min	SPN value	Settlement stability, g/cm^3
			°C×7.0MPa	Fluid loss, mL				
1.88	0.72	0.34	160	32	0	323 (1)	0.97	1.89/1.89/1.89

3.1. Conventional Performance of This System

The general performance of the preferred elasto-toughness anti-gas slurry cement slurry system is shown in Table 3.

The evaluation shows that the elasto-toughness anti-gas channeling slurry system has temperature resistance of above 160°C, good rheological properties, small API fluid loss and good slurry stability. Meanwhile, the right angle thickening is observed, the SPN value is <1, and the anti-channeling performance is good.

3.2. Evaluation on Anti-channeling Performance

(1) The evaluation of static gel strength

During cementing process, gas channeling mainly occurs in the transition period with the static gel strength of 48Pa to 240Pa. The shorter this period, the faster the internal structure of cement slurry develops, and the smaller the probability of gas channeling. The static gel strength of elasto-toughness anti-gas channeling slurry system was evaluated with static gel strength analyzer, and the results show that the transition time of static gel strength is short (only 12 min), exhibiting a strong anti-channeling performance.

(2) The evaluation of set cement permeability

After the cement slurry is solidified, large permeability of set cement will result in small resistance of gas infiltrates into set cement, and therefore, there is high possibility that gas enters the wellbore through set cement, and accordingly the risk of gas channeling will increase. The permeability of set cement formed by elasto-toughness anti-gas channeling slurry system has been evaluated. The results are shown in Table 4.

Table 4. *Set cement permeability data sheet.*

Slurry type	No	SFP1-2 dosage, %	SFP2-1 dosage, %	SFP2-2 dosage, %	Latex dosage, %	Permeability, mD
Conventional set cement	1	-	-	-	/	0.31
Elasto-toughness anti-gas channeling set cement	2	-	0.1	2	15	0.05
	3	-	0.15	2	15	0.05
	4	3	0.1	2	10	0.07
	5	5	0.15	2	10	0.06
	6	5	0.15	2	15	0.05
	7	6	0.2	2	10	0.09

The experimental data shows that the permeability of set cement can be reduced to 0.05mD by the filling of nanoparticles, which is at least 80% lower than that of conventional set cement, thus enhancing the anti-gas channeling ability of set cement and meeting the cementing requirements of set cement permeability in gas wells.

3.3. Evaluation on the Mechanical Properties of Set Cement

Test and evaluation have been conducted to investigate the influences of various dosages of elastic particles and elasticizers on elastic modulus, bending strength and impact resistance of elasto-toughness anti-gas channeling set cement, and the comparison of the set cement of this slurry system with the conventional set cement and simple latex anti-gas channeling set cement has been carried out.

(1) Analysis on the elastic modulus and bending strength

The elastic particles are filled into the space among C-S-H gels; due to their lower elastic modulus, the deformable space is formed, which increases the deformability of set cement and reduces the elastic modulus of set cement; the elasticizer is evenly distributed and scattered in set cement, which reduces the stress during the shrinkage of set cement, and the energy generated by the shrinkage is dispersed to the fiber with low elastic modulus and high tensile strength, thereby effectively enhancing the toughness of set cement. The evaluation results suggest that the elastic modulus can be reduced by up to 60%; meanwhile, as the dosage of SFP2-1 and SFP2-2 elasticizers increases, the bending strength of set cement increases as well, and the highest increment in the test is up to 84%. The microstructure of the cross section of elasto-toughness anti-gas channeling set cement was analyzed by SEM, as shown in Figure 1.

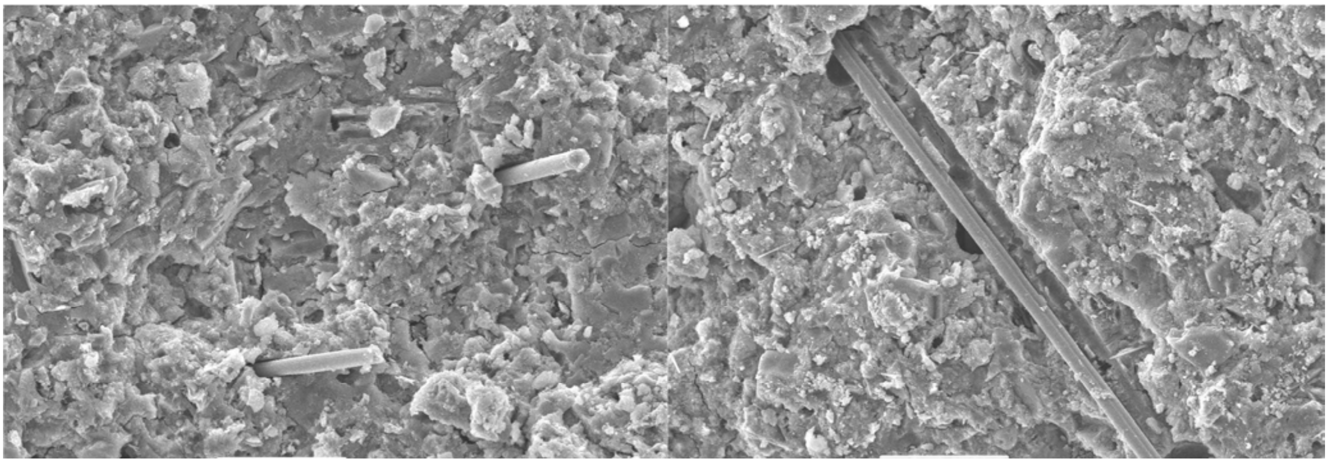

Figure 1. *Fiber distribution in set cement cross section.*

Figure 1 illustrates that stretching and peeling off status of fibers on the rupture surface of set cement specimen respectively. The morphology of the ruptured set cement specimen suggests that the fibers on the rupture surface are evenly dispersed without agglomeration. The fibers exist between the set cement crystals in the form of "micro-ribs"[14], and transmit tensile stress to set cement matrix by cohesive force and mechanical interaction, thereby realizing the tensile strength enhancement of set cement.

(2) The evaluation on impact resistance

The impact resistance of set cement is evaluated with Φ50 mm Hopkinson pressure bar tester. First, the strain gauge is attached to the input rod and output rod, and then high-pressure gas is used to drive the bullet to hit the input rod at a certain speed V_0, and the stress pulses $\varepsilon_I(t)$, $\varepsilon_T(t)$ and $\varepsilon_R(t)$ corresponding to incident wave, transmitted wave and reflected wave are measured, and finally the stress-strain curve of the material can be obtained through the data processing of three pulse signals. The curve of elasto-toughness anti-gas channeling set cement is compared with that of the conventional set cement.

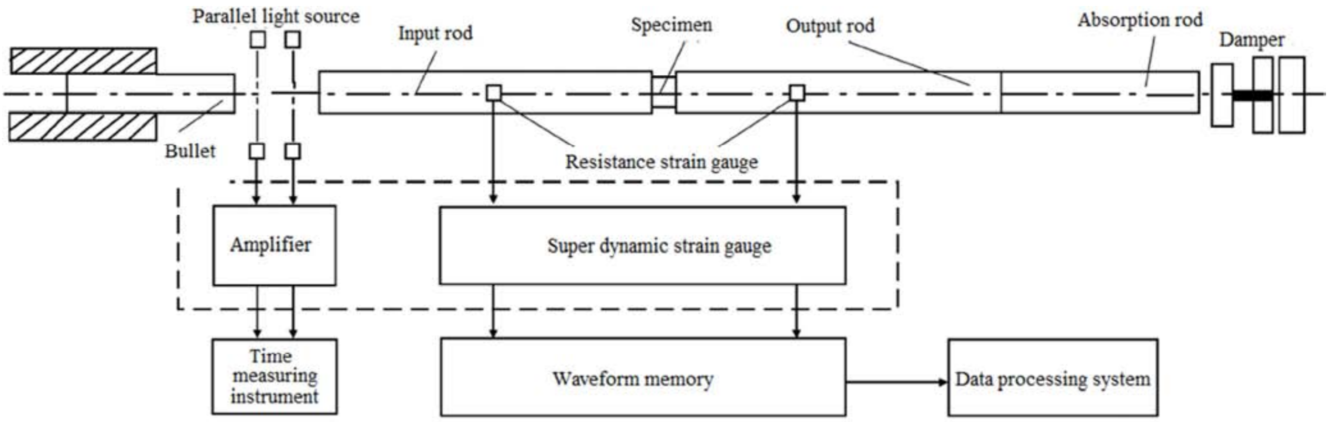

Figure 2. *Hopkinson pressure bar tester.*

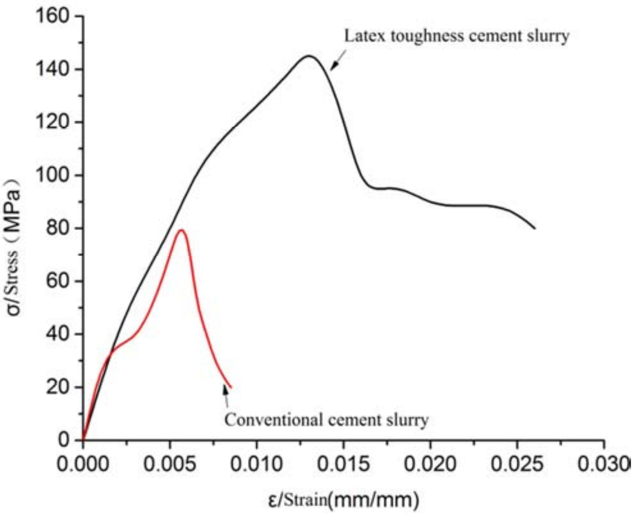

Figure 3. Set cement impact stress-strain curve.

Figure 3 illustrates that the maximum compressive load of conventional set cement is 78.16 MPa, and after adding elastic particles and elasticizers into the elasto-toughness anti-gas channeling cement slurry, the maximum compressive load of set cement reaches 145.92 MPa, which is increased by 86.69%. Moreover, the amount of plastic deformation is large, and the impact resistance is remarkably enhanced. The improvement of impact resistance and elasticity of set cement is conducive to the good integrity of set cement during the successive operations and long-term production period.

(3) Three axis stress evaluation

In order to evaluate elastic and plastic mechanical properties of set cement under constraints (confining pressure), the rock mechanics three axis stress test system is used to analyze the mechanical properties of set cement under the simulated downhole confining pressure. The designed confining pressure is 10 MPa, the size of set cement sample is Φ25 mm×50 mm, and the loading rate is 0.5～1MPa/s. The mechanical properties appraisal of set cement is conducted according to ISRM test standard.

Figure 4. Test mechanics for Three axis stress testing of rock.

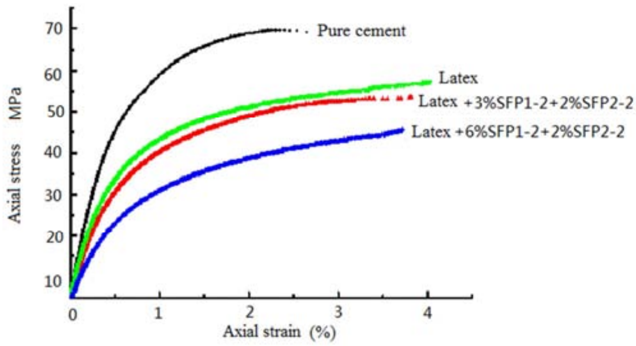

Figure 5. Set cement stress-strain curve under confining pressure 10MPa.

The axial stress and axial displacement ΔL are obtained and the length L of test sample is measured with test instrument, and the axial strain parameter $\Delta L/L$ during the loading process is established. Through comparative analysis, it is known that compared with the pure set cement, the axial strain before set cement breakage of the elasto-toughness anti-gas channeling set cement and latex set cement is increased by more than 50%, and the elastic-plastic deformation zone is increased, indicating that the hard brittleness of set cement is significantly reduced, and the mechanical deformation ability is significantly improved [15], which satisfies the elastic-plasticity need of cement ring under downhole micro-deformation conditions.

4. Field Applications

The elasto-toughness anti-gas channeling cement slurry system has been successively applied in the cementing of Φ177.8 mm liner in fourth section of ultra-deep gas wells SHN-4-1 and SHN-401 in the Shunnan block of Sinopec Northwest Oilfield Company.

Take well SHN-4-1 as an example. Well SHN-4-1 is an appraisal well in the Shunnan block. The fourth section was drilled to 6 415 m with Φ215.9 mm drill bit for the intermediate completion; the Φ177.8 mm production liner was RIH to 6 414.5 m, the measured bottom hole temperature was 162°C, and the oil/gas upward migration speed was 9.4 m/h. The well adopted the processes of sectional well killing, composite displacement, reverse circulation well washing and WOC under pressure. It also used elasto-toughness anti-gas channeling cement slurry system, and the performance of this system is shown in Table 5. 20m^3 spacer with a density 1.60g/cm^3 was pumped into the well; 26 m^3 cement slurry with a density of 1.88 g/cm^3 was pumped down; 2 m^3 fluid behind the plug with a density of 1.05 g/cm^3 was injected; total 69.5 m^3 of mud was displaced, the bump pressure is 8↗23 MPa, the water was returned normally, and picked up one stand and conducted reverse circulation for 6 hours; picked up 5 stands, and held the pressure of 5 MPa to WOC for 48 hours.

Table 5. *Cement slurry performance for Φ177.8mm liner cementing of well SHN-4-1.*

Type	Density, g/cm^3	n	K, Pa·s^n	API fluid loss, mL	Free liquid, mL	Fluidity, cm	Thickening time, min	SPN value
Lead slurry	1.88	0.82	0.55	38	0	19	372	0.72
Tail slurry	1.88	0.80	0.55	40	0	20	126	0.98

After WOC for 48 hours, POOH for SBT test, and the comprehensive cementing quality was verified to be good. The casing was pressure tested to 20 MPa, and held pressure for 30 min; the pressure drop was 0.3 MPa. The cementing design requirements were met and the gas layer was effectively sealed.

5. Conclusions

The high thermostable elasto-toughness latex cement slurry system has been successfully developed, which selected DC200 latex as high thermostable anti-gas channeling agent, used modified elastic particles to significantly reduce elastic modulus of set stone, and organic polymer fibers and inorganic mineral fibers as composite toughening materials to enhance the elasto-toughness of set cement effectively. The temperature resistance of this system can reach 160°C, with good comprehensive performance.

Compared with conventional set stones, the gas channeling by elasto-toughness anti-gas channeling set cement can be reduced by 80%; the static gel strength transition time of cement slurry is only 12 min, and the SPN value is <1, with good anti-gas channeling effect.

Compared with conventional set stones, the elastic modulus of elasto-toughness anti-gas channeling set stone can be as low as 5.4 GPa, reduced by 60%; its bending resistance is 4.8 MPa, increased by 84%; its impact load of set stone is as high as 154.9 MPa, increased by 188%; its axial strain before set cement failure under confining pressure of 10 MPa is increased by 50%. The mechanical properties of elasto-toughness anti-gas channeling set cement are excellent.

This cement slurry system has been successfully applied in 2 well times at operating depth over 6400 m in the Tarim block, with good comprehensive cementing quality being achieved. In the applied wells, the casing was tested to 20MPa and performed well, which meets requirements of cementing design and achieves effective sealing of gas layers. Therefore, this system satisfies deep and ultra-deep wells cementing.

The research results are of great reference and value for the ultra-deep wells cementing technology, which will do benefit to the safe and efficient long-term development of deep reservoirs in the Tarim Basin.

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References

[1] Tian Z. J., Zhang G. Y. The major controlling factors and pool forming pattern of oil and gas reservoirs in Kuqa Petroleum system, Tarim Basin. Petroleum Exploration and development, 2001, 28 (5): 12-16.

[2] Sun L. D., Song W. J., Jiang T. W., et al. Oil And Gas Exploration And Development In Tarim Basin And The Resource of West-to-East Pipeline Project. World Petroleum Congress, 2005.

[3] Qi L. X. Oil and gas breakthrough in ultra-deep Ordovician carbonate formations in Shuntuoguole uplift, Tarim Basin. China Petroleum Petroleum Exploration, 2016, 21 (3): 38-51.

[4] Jiao F. Z. Significance of oil and gas exploration in NE strike-slip fault belts in Shuntuoguole area of Tarim Basin. Oil & Gas Geology, 2017, 38 (5): 831-839.

[5] Teng X., Li N., Zhou B., Li J., et al. Integrated Drilling Breakthroughs Enable More Efficient Development in the Most Challenging Ultra-deep Formations in Tarim Basin, West China. SPE-170486.

[6] Zhou H., Sun M., Niu X., Zhang J., et al. A Novel Multi-Density Dynamic Well Killing Method for Ultra-Deep Wells and the Simulation System. SPE-193216.

[7] Zhang F., Yang X., Peng J., et al. Well Integrality Technical Practice of Ultra Deep Ultrahigh Pressure Well in Tarim Oilfield. International Petroleum Technology Conference. SPE 17126.

[8] Guo Y., Li X., Feng S., et al. Cementing Practices to Solve Well Integrity Challenges of Ultra Deep High Temperature Wells in Western China. SPE-182967.

[9] Jiang H., Chen M., Jin Y., et al. Wellbore Stability of the Sandstone Formation Buried in High Pressure and High Temperature Considering Radial Porous Media Flows of a Compressible Gas. American Rock Mechanics Association, 2015.

[10] Zong X. S., Xu M. B., He B. S., et al. A Method for Laboratory Evaluation of Flexible Cement Slurry. Journal of Oil and Gas Technology, 2010, 32 (6): 425-428.

[11] Guo J. Z., Luo X., Hua S. D., et al. Study on tough and anti-channeling cement slurry. Drilling Fluid & Completion Fluid, 2010, 27 (4): 59-61, 65.

[12] Tan C. Q., Liu W., Ding S. D., et al. Application of SFP Elasto-Toughness Slurry in Shale Gas Well. Petroleum Drilling Techniques, 2011, 39 (3): 53-56.

[13] Miao S. C., Ni Z. F., Wu H. P. The characteristics and qualitative analysis of basalt fiber. Technical Textiles, 2011, (10): 47-48.

[14] Zhang C. J., Leng Y. H., Li M. P., et al. Property studies and appication of leak protection and flexibility of mekralon MUD. Natural Gas Industry, 2008, 28 (1): 91-93.

[15] Li Z. Y., Guo X. Y., Yang Y. G. The methods andthe mechanisms of improving deformation capability of set cement. Petroleum Drilling Techniques, 2004, 32 (3): 44-46.