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Research Paper

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Study and Application of Combination Cementing Technology of Gypsum Salt Layer in Kuqa Piedmont Structure, Tarim Basin

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Abstract

Kuqa piedmont is the main battlefield of natural gas production in the oil field and the source of west-east gas transmission. The wellbore quality is related to the safety of well construction and production. However, the well cementation quality of the piedmont salt layer is affected by the narrow density window, low casing center degree, and narrow annular gap. Moreover, the qualified rate of well cementation has only been around 50% for many years, which seriously threatens the integrity and safety of the wellbore. Although wildcatters have conducted a series of technical research and practical exploration for many years, the actual application effect is not good. The problem of the inferior well cementation qualitied ratio in the gypsum salt layer is still prominent. Because of the above objective problems and technical limitations, this paper deeply analyzes the influencing factors of the well cementation, which has the qualitied ratio of the gypsum salt layer in the piedmont structure. Based on the three basic points of (1) casing running, (2) column centering, and (3) cementation leakage prevention, this paper studies and applies the combination cementation technology of reaming technology, coupled casing, and fine pressure control, aiming to provide new guidance for the development of the cementation operation of gypsum salt layer, the results of quality improvement and efficiency are remarkable.

Keywords: Gypsum Salt Layer, Combined Cementation, Cementation Quality, Fine Pressure Control.

Introduction

Gypsum salt layer drilling and cementation are major problems in the drilling field. The gypsum salt layer is widely distributed in Tarim, Jianghan, Sichuan, Shengli, Zhongyuan, North China, Qinghai, Bohai, and other oilfields of China.

The gypsum salt layer is a general term for halite and salts (mainly gypsum and carbonate) [1-5]. The gypsum salt layer in Kuqa piedmont of Tarim Oilfield is primarily developed in the Kumgolemu group, which are extremely thick compound salt layers (the thickest is 4200 m) and buried deeply (the deepest is 7945 m). Some well salt layers contain ultra-high pressure salt water (ρ: 2.59 g/cm^3) [6-10]. The lithology is complex, and the interaction of mudstone, salt rock, and gypsum rock is featured. The most significant characteristic of the gypsum salt layer is the creep property, which will lead to the hole diameter shrinkage, the increase of salt content of the annular slurry column, and the complex change of cement slurry performance before cement slurry hardening during cementation construction. Thus leading to poor cementation and ultimately affecting the cementing quality [7-10]. Because of the main characteristics of the gypsum salt layer, accidents such as well loss, well collapse, diameter reduction, and drilling stuck occur easily in the drilling process of the gypsum salt layer. And even serious plastic deformation and casing squeezing occur, which bring difficulties to the subsequent cementation operation. Therefore, it is of great significance to study salt paste combinational cementing technology, including reaming technology, casing with collar, and fine pressure control cementation technology.

Geological Settings

Regional Geological Characteristics and Engineering Difficulties

Characteristics of Salt-Paste Layer in Piedmont Structure

In Kuqa piedmont, the Kumgolemu Group is generally

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developed with a highly thick gypsum salt layer, and the salt mud, dolomite, and gypsum rock sections are developed from the bottom to the top. The lithologic composition is very complex and buried deeply, the pore types are diverse, and the size span of pores and fractures is large. Furthermore, gypsum rock, mudstone, carbonate rock, dolomite, and other special rock strata are mixed in the gypsum rock, which leads to multiple pressure systems in the gypsum rock. Under impurity action, overburden pressure, particle size, water content, gas content, tectonic stress, temperature, dip angle, and thickness, gypsum salt will creep, dissolve, slip, or plastic flow. The longitudinal profile also shows that gypsum salt layers alternate with thin interbedded layers, among which the salt rock layer has strong creep. As a result, gypsum is easily dissolved and collapses in the case of water. The intercalation of sand mudstone and carbonate rock is characterized by weak tensile resistance and is accompanied by the development of high-pressure brine. The characteristics of the salt-paste layer are mainly manifested in four aspects: low strength, high Poisson's ratio, elastic modulus decreases with the increase in temperature, and creep rate increases with the increase in stress and temperature.

Materials and Methods

Technical Difficulties of Piedmont Structure Salt Paste Layer Engineering

In the process of drilling and construction, it is easy to control the well trajectory due to salt creep. However, due to complex geological conditions, it is difficult to maintain the formation pressure balance under the narrow safe density window of the high-pressure brine layer and stick salt layer. Cementing operation in the process of salt bath phenomenon cause falling within the borehole wall instability or even collapse. The pasty salt layer plastic deformation will cause the hole size changes to occur under the stuck phenomenon, leading to casing layer difficulties and high-pressure brine that causes pressure changes of the annulus mud column leading to control fine pressure. Maintaining the balance of wellbore pressure in cementation operation is very difficult, and halite constantly during cement hydration hardening penetration and dissolution. The cementation quality is affected by complex conditions, such as poor cementation, casing collapse, and deformation caused by multiple nonuniform loads of structural stress on the salt paste layer in the piedmont structure. These problems easily cause complex accidents, seriously affect the normal drilling and completion speed up work in Kuqa piedmont, and cause great hidden dangers for subsequent exploration and development.

Cementing Quality in Kuqa Piedmont in Recent Years

In recent years, the cementing quality of the salt layer in Kuqa piedmont has been affected by many factors. The qualified rate of cementation has only hovered around 50% for many years, as seen in Figure 1. As shown in the following figure, the qualified rate of cementation in the salt paste layer in Kuqa piedmont was only 47.5% in 2016. It barely increased to 64.7% in 2020, seriously threatening wellbore integrity and production safety. It is urgent to study the combination cementation technology of salt paste in Kuqa piedmont.

Fig. 1 Qualified rate of cementation.

Research on Combined Cementing Technology

The combined cementing technology carried out in this paper mainly includes three aspects: reaming, coupled casing, and fine-controlled pressure cementation (Figure 2).

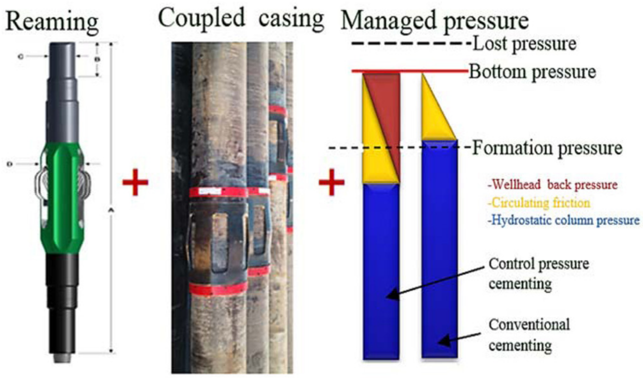

Fig. 2 Schematic diagram of combined cementation technology

Reaming Technology

In drilling and cementation operations, reaming techniques are almost always used to control gypsum salt creep. This technology has the advantages of casing cementation of small clearance, improving cementation quality, solving drilling problems in reduced diameter sections, and supporting new drilling and completion technology.

At the same time, the selection of reaming parameters and tools plays a significant role in the final reaming safety and effect.

The expanded reamer used in this manuscript can be replaced or opened, or retracted according to the process requirements, while the larger reamer size makes the shaft wall smoother, as seen in Figure 3.

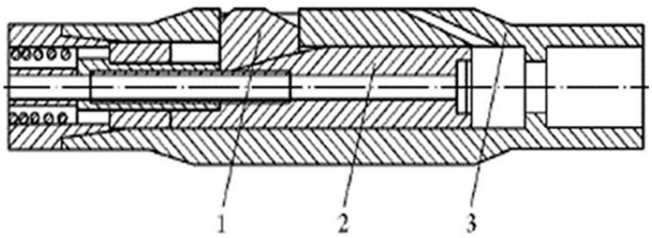

Fig. 3 Schematic diagram of basic structure of reamer.
1-blade; 2-Control components; 3-ontology

In the case of the Ø215.9 mm borehole, the reamer solution, first, used the Ø215.9 mm bit plus the reamer bit (304mm) to expand the borehole diameter to 304 mm, and then, it ran a dilated reamer (444.5 mm) to expand the borehole diameter to 444.5 mm.

Reamer assembly: First run Ø215.9mm tooth wheel drill head + reamer drill head (304mm) + Ø159 mm drill collar × 5 columns + conversion joint + Ø127mm drill pipe; then run the Ø304mm tooth wheel drill head + reamer (444.5mm) + Ø159mm drill collar × 5 string + conversion joint + Ø 127mm drill pipe.

Coupled Casing

Salt rock and gypsum salt are plastic layers that undergo plastic creep under high temperatures and pressure, resulting in great extrusion pressure and casing breakage. This pressure is related to the pressure of the overlying strata, and the pressure coefficient is as high as 2.3 to 2.7, which is much higher than the external squeeze calculated using the annulus fluid column pressure. Therefore, the conventional casing cannot support it. Therefore, based on theoretical calculation and practice, innovative research and development of high-strength small coupled casing, on the premise of not reducing the casing anti-extrusion strength (Formula 1~2) and anti-internal pressure (Formula 3~4), not only meet the centralizer placement but also reduce the risk of casing stuck, laying the foundation for casing centralizer placement.

The external extrusion strength is calculated by:

$$P_{ca} = [\sqrt{1-\frac{3(S_a+p_i)}{4Y_p^2}} - \frac{S_a+p_i}{2Y_p}]P_{co} \quad (1)$$

$$P_{co} = \frac{b^2-a^2}{2b^2}Y_p \quad (2)$$

where P_{ca} is an equivalent compressive force under three-dimensional stress (MPa),

S_a is axial stress (MPa), calculated as effective circumferential force (considering buoyancy), P_i is internal stress (MPa), Y_p is minimum yield force of casing steel (MPa), and a, b are casing radius (mm).

The internal pressure strength (MPa) is calculated by:

$$P_{ba} = [\sqrt{1-\frac{3b^4}{3b^4+a^4}\left(\frac{S_a+p_e}{Y_p}\right)^2} + \frac{a^2}{\sqrt{3b^4+a^4}}\frac{S_a+p_e}{Y_p}]P_{\mathrm{bo}} \quad (3)$$

$$P_{bo} = \frac{b^2-a^2}{\sqrt{3b^4+a^4}}Y_p \quad (4)$$

where P_{ba}= Equivalent internal pressure resistance of thick wall casing under three-dimensional stress (MPa), P_e= Outside pressure (MPa), and S_a= Axial stress (MPa), calculated as effective circumferential force (considering buoyancy).

Therefore, the following types of casing with coupling were designed, and the specific parameters are shown in Table 1.

Table 1 Basic parameters of the coupled casing.

Name of the casing	Size (mm)	Coupled diameter (mm)	Internal compression strength (MPa)	External compression strength (MPa)
206.38 mm×17.25 mm 140HC Small collar casing	168.70	220.14	123.4	150.0
265.13 mm×22.00 mm 140HC Small collar casing	217.16	279.48	115.4	150.0
273.05 mm×26.24 mm 140HC Small collar casing	216.60	287.48	133.6	180.0
293.45 mm×23.55 mm 140HC Small collar casing	242.38	309.28	111.8	145.0

To ensure the cementing quality of the gypsum-salt combination, we also put forward the requirements of casing placement, displacement efficiency, and specific cement slurry design in addition to the conventional cementing process. To ensure the casing in the medium is more than 65% to gain higher displacement efficiency, we not only on the choice of cleaning borehole, spacer, casing, and other aspects but also through the casing in the moderate and the relationship between the critical Reynolds number, Angle and centralizer spacing relationship, finally adopted a casing placed a monolithic play way. As a result, the casing level was increased from 25% to 70% (50% deviated), significantly improving the displacement environment (Figure 4).

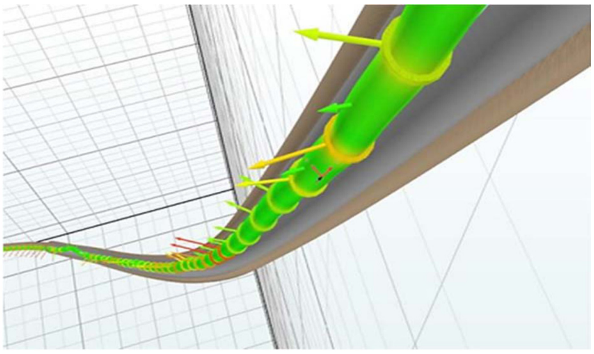

Fig. 4 Schematic diagram of casing elevation in salt layer.

Fine Pressure Control Cementing Technology

Conventional cementation uses hydrostatic column overbalance to carry out casing running and replacement cement slurry, which can easily cause annular pressure imbalance due to the process of casing running pressure, high friction resistance of injection replacement, and weight loss due to waiting time, which can no longer meet the cementation needs of formation with narrow safe density window. Thus, the concept of "fine pressure control" in cementation, forming a fine pressure control cementation technology, has been extended in the present study.

Fine pressure control cementation is inseparable from the fine pressure control system, which includes automatic throttling control, backpressure compensation, monitoring and control, PWD and high pressure wellhead rotary seal, as seen in Figure 5. The system has the following characteristics:

1- Servo motor throttle drive mode, system pressure control precisely, accurately and fast (response time ≤ 0.5 s, fully open to fully closed < 10S, wellhead pressure control accuracy ± 0.1 MPa);

2- High precision of wellbore pressure control (a precise control method of wellbore pressure was established by mutual verification of hydraulic model and PWD data and modification of hydraulic model with stored manometer data, with calculation accuracy up to 95%);

3- multiple blocking design and high security (two automatic, one manual, has been all through the channel to meet a variety of working conditions, automatic throttle system has a variety of blocking mechanism to avoid the occurrence of channel blocking jump, equipped with emergency power supply unit, temporary blackout system can still work normally);

4- it can realize continuous circulation fine pressure control (developed valve type continuous circulation system, combined with automatic throttling control system, to achieve single root connection and uninterruptable circulation during tripping, to solve the problem of easy accumulation of gas and easy deposition of cuttings after stopping the pump of horizontal Wells);

5- It has multiple warning functions (3D virtual geological environment downhole risk warning and abnormal alarm functions are developed, which it can prompt the corresponding complexity of adjacent wells, abnormal warning of key parameters such as opposite pressure, casing pressure, suspension weight and flow rate, and sound and light alarms for overflow).

Fine point pressure cementation technology first establishes fine control cementation design method of control parameters of casing design, injection molding for dynamic simulation, pressure-out setting scheme, and another submodel, developed a special design software, realize the parameters of the casing, drilling fluid density and performance, plasma column structure, displacement, accurate quantitative design parameters such as wellhead casing pressure. The integrated equipment, monitoring, and control system of fine pressure control and compensation for cementation have been developed, which has multiple functions such as the acquisition of all cementing parameters, real-time calculation and dynamic control of annular pressure profile, and alarm of key parameters.

Fine-control cementing technology has four advantages: no production and three improvements, which are to achieve bottom hole pressure balance and ensure that brine does not flow; and it increases slurry density difference and improves displacement efficiency; Furthermore, it releases cementation displacement to improve displacement efficiency; Moreover, it increases rheological adjustment space, and it improves displacement efficiency.

In general, compared with other cementing technologies, the combined cementing technology has a more reasonable combination of well structure and annulus fluid column, which can increase the detection and control of salt plaster creep rate, balance pressure, and improve the detection and control of salt plaster creep rate, balance the casing moderate and displacement efficiency.

Matters Needing Attention and Scheme Design for Cementation in Gypsum Salt Layer

Precautions for Cementation in Gypsum Salt Layer

High-density saturated brine drilling fluid or water-in-oil drilling fluid should be used in gypsum salt layers to form regular boreholes and create conditions for high-quality cementation. Before running the casing into well, the well should be checked repeatedly to ensure that casing can be run without blockage.

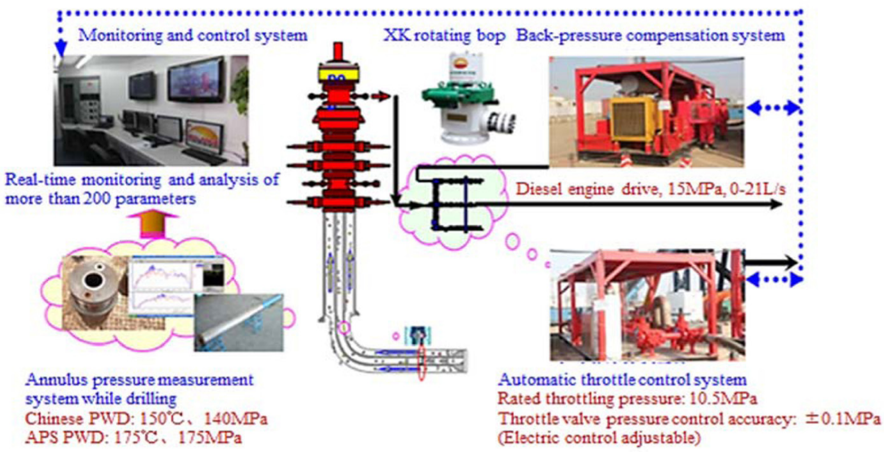

Fig. 5 Fine pressure control equipment diagram.

Reaming technology should be adopted to ensure a thicker cement ring and improve cementing quality. Following the design of the high-strength casing, it is best to use about 30 m transition wall thickness casing in the salt rock section to avoid stress failure. The salt paste layer and its upper and lower sections ensure the number of centralizers to center the casing.

Choose the cement slurry system matching the salt paste layer, cement as high as possible to reduce casing damage. Complete cementation as soon as possible after the casing is fully in the well. High-density cement slurry was used to balance the creep stress of the salt paste layer from the bottom hole to 250 m above the salt layer.

The good fluidity of cement slurry has been ensured, thereby improving displacement efficiency. Furthermore, with the use of fine pressure control means of annular pressure waiting for coagulation; Properly, the waiting time of the cement slurry drilling plug is extended.

Cementing Scheme Design of Gypsum Salt Layer

Controlled pressure cementing determines safe density window in advance according to the design of drilling fluid density, the density of slurry density window, time-sharing displacement, time-sharing controlled pressure, wholly in control parameters strictly control pressure cementing technology, always, control the bottom hole pressure within the scope of the safe density window, prevent leak, design control pressure cementation plan (as seen in Figure 6) to improve the cementing quality.

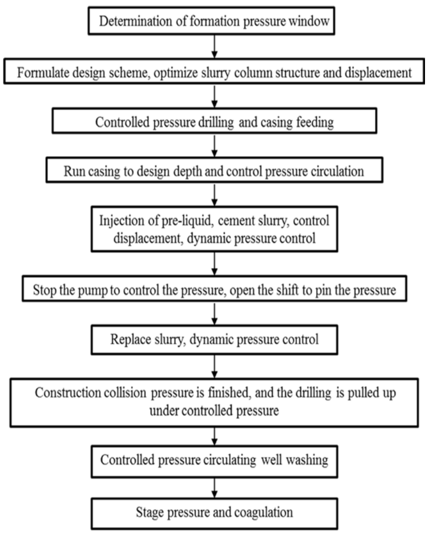

Fig. 6 Design diagram of cementation scheme for gypsum salt layer.

Results and Discussion

Field Application of Gypsum Salt Layer of Combination Cementation Technology

Taking a well in Keshen, Tarim piedmont structure as an example, based on the fine control pressure cementation technology of one-time up-return, the anti-squeeze cementation measures are used. The two-set cement slurry system is adopted, the two-set interface is 6900 m, the quick-dry cement slurry is sealed 6900-7297.5 m, and the slow-set cement slurry is sealed 6479.503-6900.00. The upper plug is 200 m, and the lower plug is 216.994 m. The pump was started to inject spacer, slow coagulation, fast drying, spacer, and displacement drilling fluid successively, and the bottom hole equivalent was controlled between 2.55 and 2.57 g/cm³ during the whole cementation operation (2.2 MPa controlled pressure on the pump, 6 MPa controlled pressure on the pump and 7.5 MP a controlled pressure on the driller).

No overflow or leakage occurred in the combined cementation process, which successfully realized an upward return, reduced the procedure of positive injection and reverse squeeze, significantly reduced the mid-completion period, increased the displacement of cementation in the salt layer (average return rate of 1.1m/s compared to 0.8 m/s in the past), and increased the density difference between drilling fluid and cement slurry (0.09g/cm³, compared to 0.05g/cm³ in the past). For the first time, cementation ECD (Equivalent Circulating Density) was lower than drilling ECD, as seen in Figure 7. It provides good technical support for improving cementation displacement efficiency in salt zones.

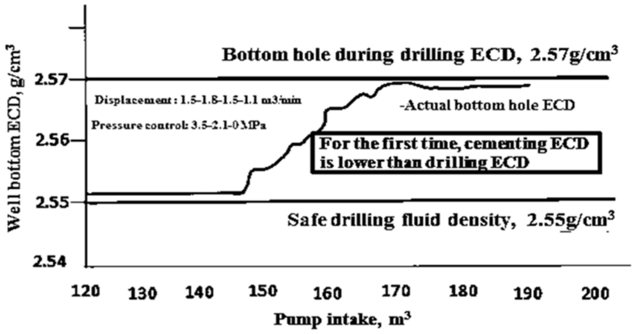

Fig. 7 Combined cementing construction effect.

According to the cementing quality of several gypsum salt wells, recently, the average cementing qualification rate of the applied wells has increased from 65.9% to 92.5% by integrating the three key tools to shape the gypsum salt cementing technology. Compared with conventional cementing technology, this technology can save RMB 2.168 million yuan per well (compared with the recovery of cementation loss and reverse squeeze). Moreover, it is estimated to save RMB 43.36 million yuan for the whole year after the promotion, showing significant economic benefits (Table 2).

Table 2 Cost savings per well after the application of the technology.

	Category	Unit price	Number	Save cost (RMB)
	Reaming tools	0.15	1000	1500 thousand
	Pressure control equipment	6	10	600 thousand
	Casing centralizer	0.2	60	12 thousand
	Casing cost	0.1	100	100 thousand
	Comprehensive daily fee	10	9	900 thousand
	Drilling fluid cost	1	300	3000 thousand
	Cement cost	0.7	40	280 thousand
Total				thousand

Conclusions

According to the above application and benefit analysis, the combined cementation technology of the salt layer breaks through the traditional cementation practices of 30 years in front of the mountain salt layer in the Tarim oilfield (adding centralizer and realizing drilling without leakage, thus cementation without leakage). The application of three powerful tools has achieved the application effect of "1+1+1>3" and earned a major breakthrough in the cementation quality of the salt layer (50% to 90%). The continuous improvement of well integrity provides solid cementation technology support for the safe production of HTHP gas wells, with broad application prospects.

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