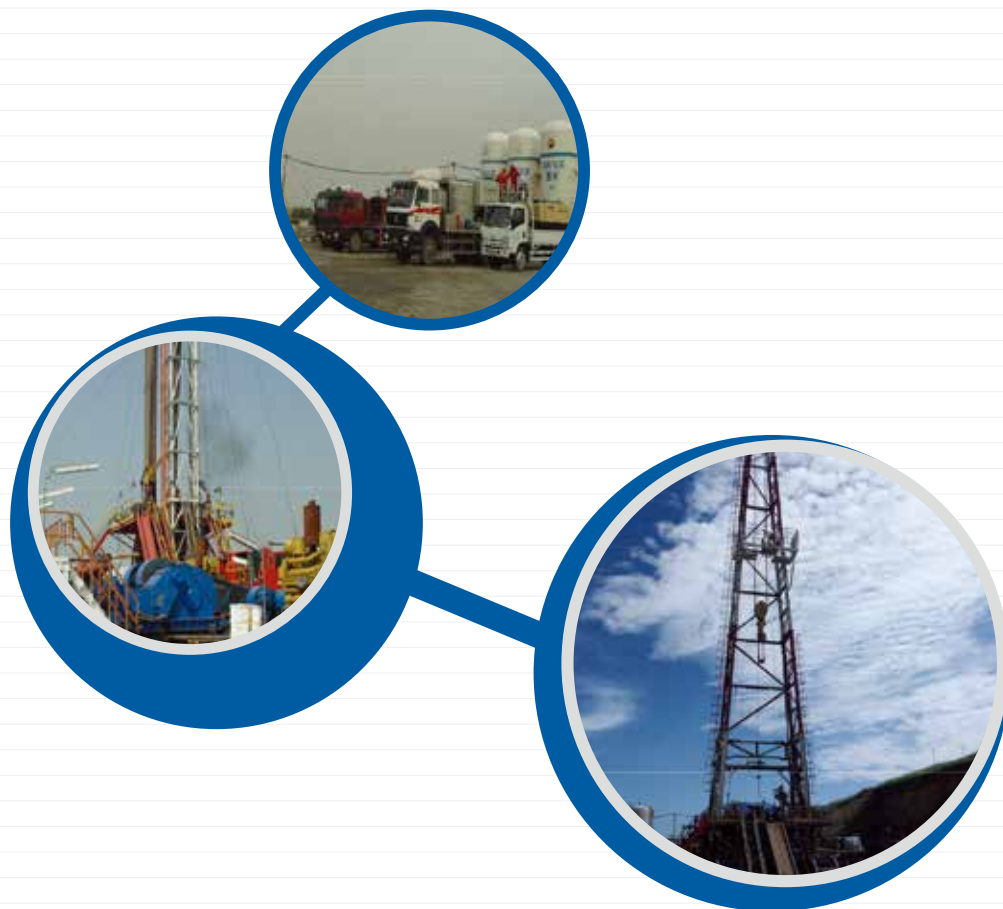


Complex Oil and Gas Well Cementing Technologies

Science & Technology Management Department, CNPC

2015



CHINA NATIONAL PETROLEUM CORPORATION

*Complex Oil and Gas Well Cementing Technologies:
Strengthening the foundation and body of oil and
gas exploration and development!*





Contents

1	Introduction	3
2	Characteristic Technologies	4
3	Typical Cases	14
4	Scientific Research Equipment	20
5	Qualification Standards	21
6	Expert Team	22



CNPC

China National Petroleum Corporation (CNPC) is a state-authorized investment agency and a state holding company. On July 1998, with the implementation of the Institutional reform of the State Council, CNPC was reorganized to become an integrated oil company of cross-regions, cross-industries and cross-countries, it adopts modern enterprise system to realize the integrations of upstream and downstream operations, internal and external trade, production and marketing. CNPC's business covers six main sectors: oil and gas operations, petroleum engineering service, petroleum engineering construction, petroleum equipment manufacturing, financial services and new energy development. In 2014 CNPC produced 113.67 million tons of crude oil and 95.46 billion cubic meters of natural gas, while crude processing volume reached 150.2 million tons. The total revenue of RMB 2,730 billion with a profit of RMB173.4 billion had been achieved the same year.

CNPC was ranked 3th among the world's largest 50 oil companies and 4th in Fortune Global 500 in 2014.

CNPC strictly follows by the combined strategies of increasing resource capacity, expanding market shares and consolidating the international role, and persists in regarding technical innovation as a key framework to advance technological progress. To develop its core businesses, focuses will be placed on the solutions of key bottleneck technologies and key proprietary technologies. Thanks to continuously improving of the technical innovation system, optimizing the configuration of technological resources and strengthening the construction of strong talent teams, CNPC's technological creativity has been considerably upgraded. Consequently, a large number of technologies have been developed independently, with its own intellectual property.

The complex oil and gas well cementing technologies is one of representatives for major innovations of CNPC.

OFFERING ENERGY SOURCES, CREATING HARMONY

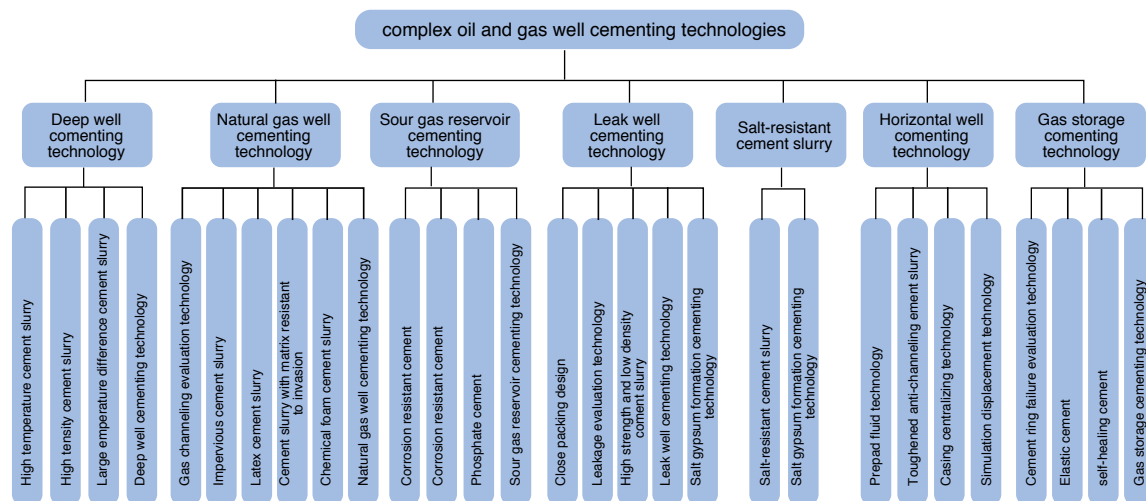
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INTRODUCTION

With the expansion of oil and gas exploration and development towards deep strata and new fields, drilling and completion engineering is confronted with cementing problems under complex geologic conditions and operating conditions involving HTHP, salt gypsum formations/brine formations, sour gas reservoirs, long cemented sections, etc. Through decades of research and accumulation, CNPC has formed frontier cementing theory achievements including close packing theory, anti-channeling evaluation method, cement ring failure evaluation, etc. as well as complex oil and gas well cementing technologies including deep well cementing technology, leak well cementing technology, salt gypsum cementing technology, horizontal well cementing technology, gas storage cementing technology, etc. and developed 18 types of additive series products and 18 sets of cement slurry and prepad fluid systems including salt-resistant fluid loss additive, salt-resistant latex, large temperature difference retarder, deepwater casing cement, self-

healing cement, elastic cement, etc. They have been successfully applied in CNPC's overseas oil and gas operation areas and oil and gas exploration and development projects of 26 domestic oilfields. The minimum density of cement slurry is 0.9g/cm^3 and the maximum density 3.2g/cm^3 . The applicable highest temperature is 240°C and the applicable lowest temperature 4°C . The largest length of the section cemented at a time reaches to 5155m, and the maximum temperature difference above and below the cemented section is over 100°C .

Complex oil and gas well cementing technologies have been awarded with 10 national authorization patents and 26 national, provincial and ministerial science and technology advance prizes. With the technologies, 13 national and provincial and ministerial key new products have been worked out. Over 30 technical standards have been formed and CNPC has passed API Q1 quality management system certification.



2 CHARACTERISTIC TECHNOLOGIES

2.1 Deep well cementing technology

Deep well cementing technology mainly involves high temperature cement slurry, high density cement slurry, large temperature difference cement slurry and matching cementing technologies and is intended mainly to solve complex cementing problems involving HTHP, narrow annulus, narrow safety density window, long cemented section, etc.

High temperature cement slurry Prevent high temperature strength retrogression of set cement by analyzing the crystalline phase of cement hydration products in high temperature environment and adjusting C/S. Develop cement additives such as high temperature retarder BCR-300L, high temperature resistant fluid loss additive BXF-200L, etc. The maximum temperature of cement slurry reaches 190 °C (BHCT); the strength of set cement doesn't regress at 358°C ; the comprehensive performance of cement slurry meets engineering requirements.

High density cement slurry Weighting materials such as BCW-500S, BCW-550S, etc. and dispersants such as BCD-210L and CF40S have been developed. Through close packing optimization design, the highest density of cement slurry can reach 3.20g/cm³ and the 24 hours compression strength is larger than 14MPa. The system has good rheological property

and sedimentation stability and can effectively stabilize formations and prevent high pressure formation fluids from leaching out.

Large temperature difference cement slurry A large temperature difference retarder BCR-260L has been developed to solve the problem on slow strength development or ultra-slow setting of top cement slurry in a long cemented section of a deep well. When the static temperature difference above and below a cement slurry section is 100°C , the 48 hours compression strength of top set cement is larger than 3.5MPa. The applicable temperature of large temperature difference cement slurry is 70~180°C .

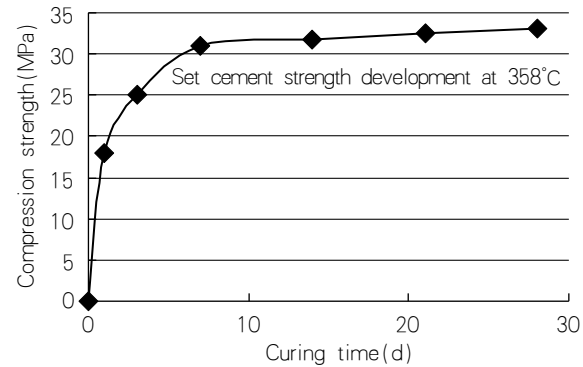
Deep well cementing technology Safety coefficient is appropriately increased in the casing design. The casing design specially considers the factors such as possible maximum wellhead pressure and bottom hole pressure, casing wear, bending moment, creep formation and other factors during production. Staged cementing technology and one-time return cementing technology for long cemented sections or liner (sometimes tieback) cementing technology are used. Before cementing, drilling fluid property is adjusted appropriately and prepad fluid system is used to improve narrow annulus displacement efficiency.



Packer type liner hanger



Hydraulic stage cementer



30 days strength development curve of 358°C set cement

2.2 Natural gas well cementing technology

Natural gas well cementing technology mainly includes gas channeling evaluation technology, impervious cement slurry, latex cement slurry, cement slurry with matrix resistant to invasion, chemical foam cement slurry and natural gas well cementing technology and is intended mainly to solve natural gas channeling problems.

Gas channeling evaluation technology Carry out inversion of pore pressure of cement slurry by testing the static gel strength of cement slurry. Evaluate the anti-channeling capacity of annular cement slurry, predict the occurrence possibility of channeling after cementing and thus provide guidance to cement slurry system optimization, formula design and technological measure formulation using the effective stress principle, finite element analysis method and scaling down method in combination with actual hole parameters.

Impervious cement slurry Impervious fluid loss additives such as G60S, W99, and so on, have been developed. Using polymer crosslinking technology, polymers form a network structure in cement slurry to increase gas migration resistance; under the action of differential pressure, cement slurry forms tenacious impervious membranes on borehole wall to prevent gas channeling from occurring.

Latex cement slurry Increase the resistance of latex to temperature, salt and multiply charged ions through latex particle design, monomer proportioning optimization and selecting reactive emulsifiers. A special cementing latex BCT-880L has been developed. Depending on the blockage and pressurized film forming characteristic of latex micro-particles in cement slurry, gas channeling is prevented in cement slurry solidification period. The applicable temperature range of latex cement slurry is 30~190 °C. Latex cement slurry can resist saturated brine and is applicable to oil and gas well cementing operations with high gas channeling risks.

Cement slurry with matrix resistant to invasion Anti-channeling agent with matrix resistant to invasion BCG-200L has been developed. The agent can increase the liquid phase viscous force of cement slurry, shorten gel transition time, increase fluid migration resistance and prevent oil, gas and water channeling from occurring. The applicable temperature range is 30~190℃. The cement slurry is resistant to saturated brine and applies to cementing operations in formations with active oil, gas and water channeling.

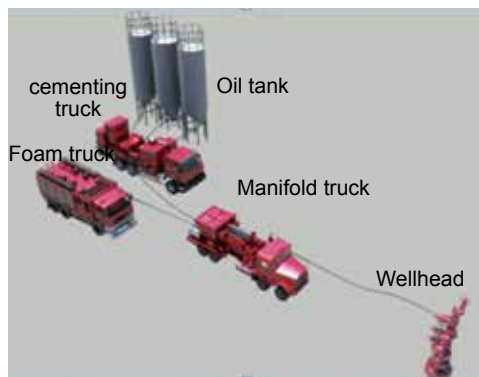
Chemical foam cement slurry Chemical gas formers such as FCA and FCB and foam stabilizer FCF have been developed. Gas is generated through chemical reaction, thus causing the gas pressure

trapped in cement slurry to be larger than formation pressure and preventing gas channeling. Chemical foam cement slurry is characterized by stable foam, low density, high strength, low permeability, low heat conductivity, etc. The lowest surface density of chemical foam cement slurry can reach to 0.42g/cm³. Chemical foam cement slurry simplifies the complex surface equipment for mechanically aerated cement slurry.

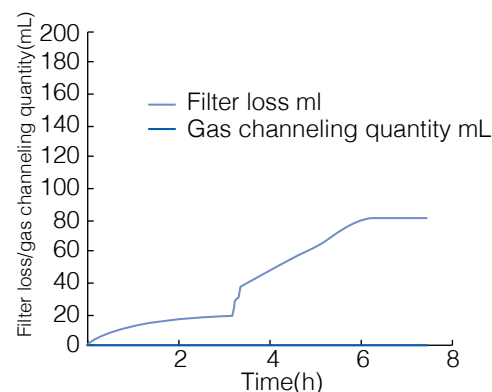
Natural gas well cementing technology The cementing technology includes gas tight pipe string structure design, three-pressure prediction, three-pressure stable cementing technology design and cement slurry system optimization.



Comparison of salt-resistant latex
with common latex



Foam cement operation technology flow
schematic



Anti-channeling test of salt-resistant latex

2.3 Sour gas reservoir cementing technology

Sour gas reservoir cementing technology mainly includes corrosion evaluation technology, corrosion resistant cement, phosphate cement and matching cementing technology and is intended mainly to solve cement ring corrosion problems in acid gas.

Corrosion evaluation technology Evaluate the corrosion degree of set cement at temperature and partial pressure of acid gas and provide guidance to corrosion resistant material development, corrosion resistant cement slurry design and cement ring life prediction by analyzing the compression strength, permeability and corrosion depth of set cement and crystalline phase variation of hydration products.



Corrosion resistant set cement

Corrosion resistant cement A corrosion resistant material BCE-750S which doesn't react with acid gas chemically has been developed. The material can reduce the alkalinity and permeability of set silicate cement and the corrosion degree of set cement and slow down the invasion speed of acid gas. The operating temperature of corrosion resistant cement is 50~180°C (BHCT).

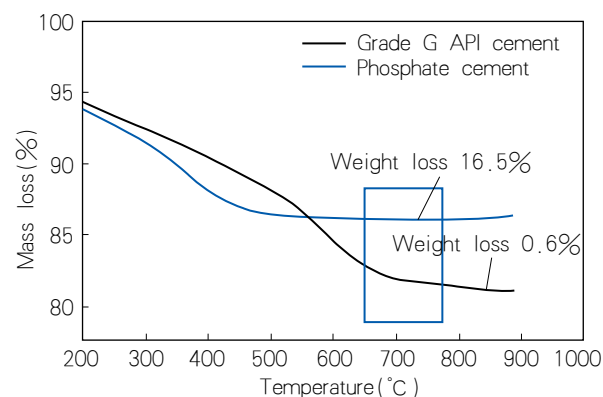


Conventional set cement

Section corrosion depth after corrosion (set cement curing condition: 120°C, 5MPa CO₂, 14 days)

Phosphate cement Phosphate cement is an excellent gelling material resistant to corrosion of CO₂ and H₂S. Its hydration products don't chemically react with acid gas. Matching additives such as BCF-600L fluid loss additive, BCR-600L retarder, etc. dedicated to phosphate cement have been developed, so that the prepared phosphate cement can meet oil and gas well cementing requirements. The applicable highest temperature range is 150°C (BHCT) and the temperature resistance reaches 370°C. Phosphate cement can be used in cementing operations in sour gas reservoirs, geothermal wells, SAGD wells, etc.

Sour gas reservoir cementing technology Select casing, accessories, tools and cementing materials resistant to acid gas.



Thermal weight loss comparison curves of set cement corroded for 7 days at 100°C and 5MPa CO₂ partial pressure

2.4 Leak well cementing technology

Leak well cementing technology mainly includes leakage evaluation technology, close packing design, anti-leakage cement slurry, high strength and low density cement slurry and leak well cementing technology and is mainly intended to solve problems involving insufficient TOC, missing reservoir sealing, bad cement ring cementation, oil, gas and water channeling, etc. caused by lost circulation during cementing.

Close packing design Make a microscopic analysis based on materials and increase the stacking volume of dry mixing materials (PVF). Improve the surface property of materials, reduce the filler water between material particles and the lubrication water on material surface, further increase the solid phase in unit volume of cement slurry, and form tighter set cement. Remarkably improve the comprehensive performance of low density cement according to the physical and chemical reaction of materials, optimized filling materials and certain affinity and reaction activity of cement. Establish the numerical analysis method for multi-system close packing design based on compressible packing model, and provide guidance to the design of high performance and low density cement slurry.

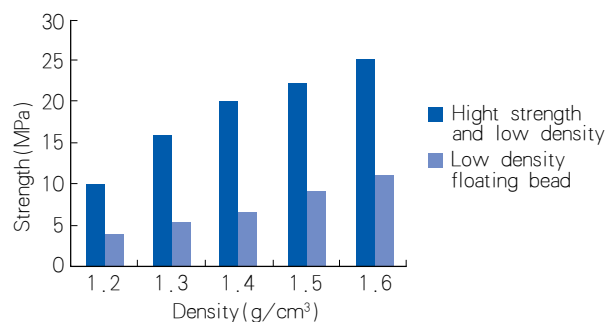
High strength and low density cement slurry

Light-weight reinforced materials such as PZW, BCE-600S and so on have been developed based on close packing design, thus resolving the contradiction between cement slurry operation performance (density, rheological property, etc.) and cement ring mechanical property (strength, permeability, etc.). The 24 hours compression strength of set cement with its lowest density of 0.9g/cm^3 is larger than 14MPa, so

that the performance of low density set cement can be comparable with that of conventional density set cement and the technical requirements of cementing in easily leaked long cemented sections with low pressure are satisfied.



Close packing model

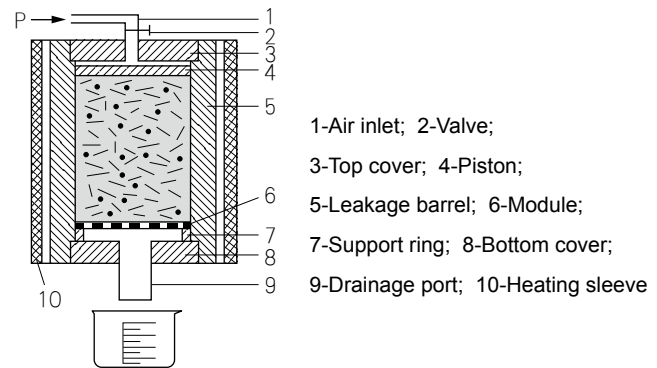


Strength comparison of ultra-low density set cement

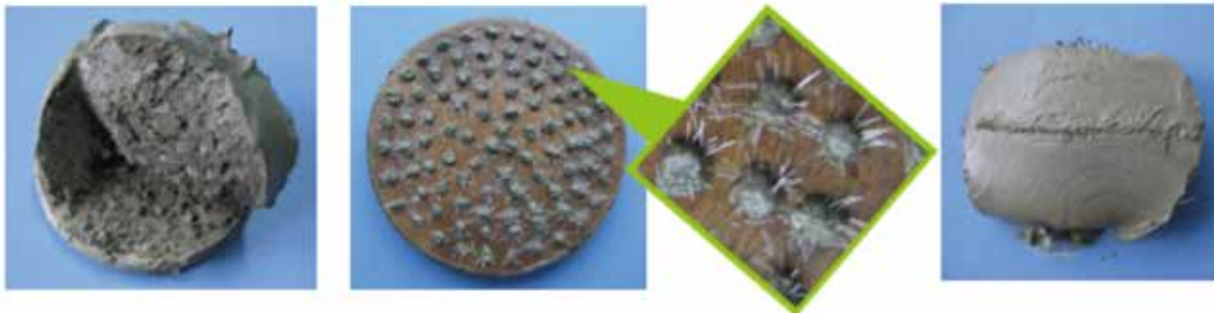
Cement slurry leakage evaluation technology

Simulate permeable or fractured leak formations with an experiment unit; measure the leak rate of cement slurry on different percolation media at the given differential pressure; evaluate the anti-leakage capacity of cement slurry system and provide guidance to cement slurry formula optimization and anti-leakage cement slurry design.

Anti-leakage cement slurry A special fiber lost circulation material BCE-200S has been developed based on bridging leakage stoppage and close packing design to prevent and reduce leakage in permeable and fractured formations. In case of 1mm wide fissures and 2mm wide pores, the pressure bearing capacity can be increased by over 3.5MPa, the applicable temperature reaches 150 °C , and the applicable density range is 1.3~2.6g/cm³.



Leakage stoppage device schematic



1mm pore leakage stoppage effect chart

1mm fissure leakage stoppage filtration cake

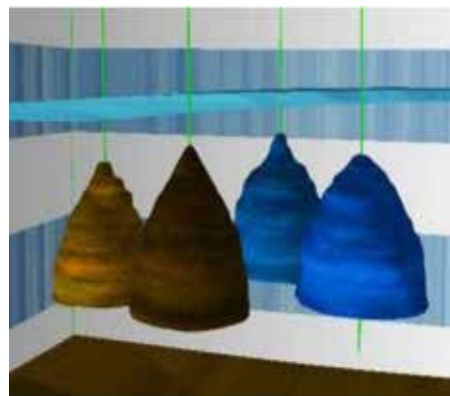
Leak well cementing technology Determine formation bearing capacity and leak zone location, strictly control casing running speed, and reasonably design the density and length of annular working fluid according to actual drilling data, logging data and hydraulic calculation. The lost circulation materials such as acid-soluble consolidation materials etc. are used in drilling process to increase formation bearing capacity and create good conditions for cementing. When meets high lost circulation risks, the positive injection and reverse squeeze technology is used to ensure cementing operation safety. Determine the main factors for cementation quality through cementing process simulation and provide guidance to cementing design.

2.5 Salt gypsum formation cementing technology

Salt gypsum formation cementing technology mainly includes salt-resistant cement slurry and matching salt gypsum formation cementing technology and is intended mainly to solve the problems including bad impact of salt gypsum formations on cement slurry property, bad cement ring cementation caused by salt gypsum formation solution corrosion, etc.

Salt-resistant cement slurry Salt-resistant additives such as BCF-200L, BCF-200S, etc. have been developed. With them, flocculation and ultra-slow setting of cement slurry will not occur and the integral performance of cement slurry keeps stable. The cement slurry can resist saturated brine and the applicable temperature range is 30~190 °C . The cement slurry is applicable to cement operations in brine formations, salt rock formations, salt gypsum formations, alkaline formations, salt cavern type gas storages, etc.

Salt gypsum formation cementing technology Saturated or semi-saturated brine cement slurry is used in cementing to avoid salt gypsum formation corrosion. Determine appropriate operation parameters, select appropriate salt-bearing prepad fluid system, and improve displacement efficiency under irregular hole conditions through computer simulation.



Cementing of Jintan salt cavern
type gas storage

2.6 Horizontal well cementing technology

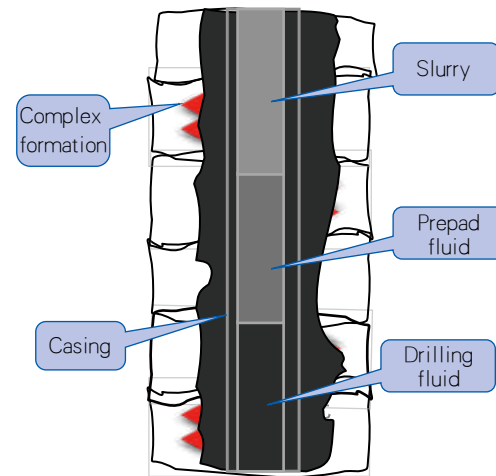
Horizontal well cementing technology mainly includes prepad fluid technology, toughened anti-channeling cement slurry, casing centralizing technology and simulation displacement technology, is intended to solve the difficult problems including cuttings sedimentation bed, difficult pipe string centralizing, impact of oil base drilling fluid on interface cementation quality, high cement ring integrity requirements, etc., and meets the needs of subsequent reservoir stimulation.

Prepad fluid technology A BCS prepad fluid system has been developed. BCS-110L washing fluid has strong percolation effect and oil washing characteristic, is favorable for filtration cake removal and drilling fluid displacement, realizes interface reversal of oil base drilling fluid, and improves cementation quality. BCS-040S spacer fluid has strong isolation effect and suspension stability as well as good compatibility with drilling fluid and cement slurry. The prepad fluid has good rheological property and is easy to reach turbulent flow. The applicable temperature is 20~180°C .

Toughened anti-channeling cement slurry

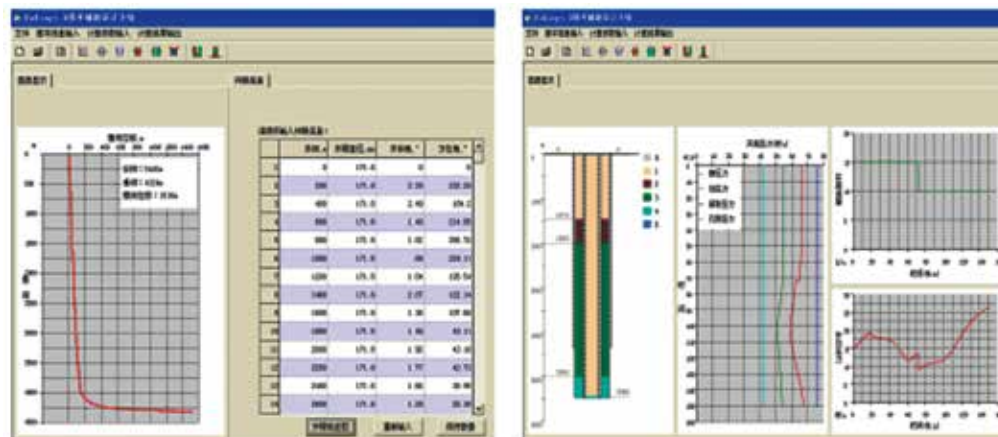
BCG-300S toughened anti-channeling agent has been developed and it is a flexible polymer resin with latex characteristics. Flexible micelles are formed in cement slurry. They prohibit percolation, generate micro-expansion, prevent fluid invasion, increase the tenacity of set cement, and remarkably improve the mechanical property of set cement. The applicable temperature range is 30~150 °C . The cement slurry is applicable to cementing operations in non-conventional wells including horizontal wells etc. and natural gas wells.

Horizontal well cementing technology mainly including: simulation displacement technology, casing centralizing technology and casing flotation technology. Casing design simulation software has been developed. With the software, the processing of casing centralizing and cementing displacement is optimized and designed. In addition, determine casing



Slurry column structure of cement ring in annulus

centralizer type and installation location, optimize operation parameters, predict operation risks, and evaluate displacement effect.



Displacement process simulation with software

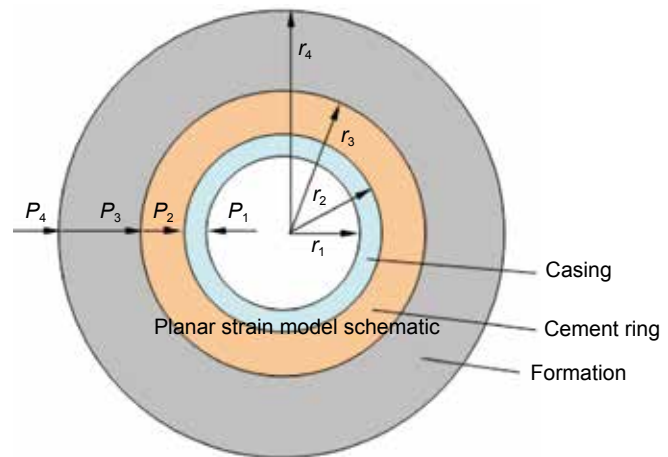
2.7 Gas storage cementing technology

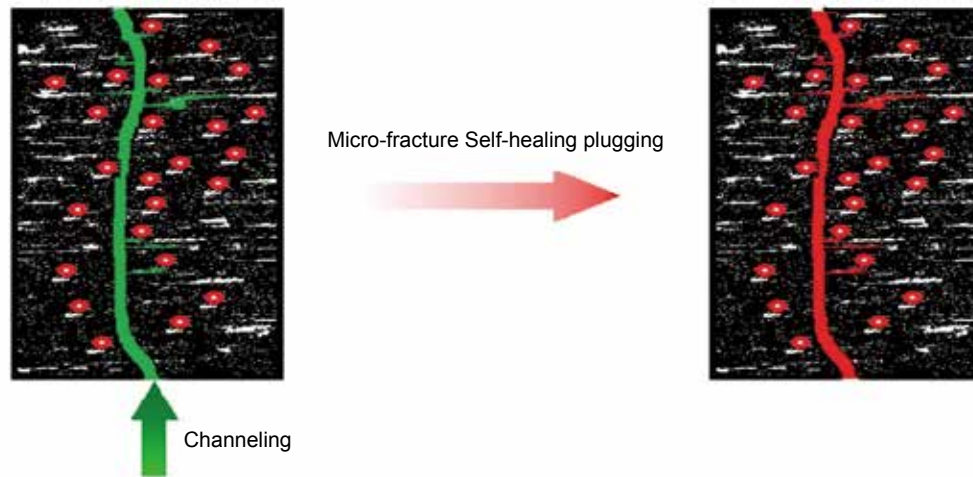
Gas storage cementing technology includes cement slurry technologies such as anti-channeling latex cement slurry, elastic cement, self-healing cement, salt-resistant cement slurry, etc., cement ring failure evaluation technology, displacement efficiency improvement analysis, cementing process simulation, etc. and is intended mainly to solve the cement ring sealing failure problem caused by alternate variation of well bore pressure in gas storage well injection-production process.

Cement ring failure evaluation technology By establishing the mechanical model for downhole cement ring stress analysis, quantitatively evaluate the integrity of cement ring with alternate variation of pressure in pipe string, propose the mechanical property requirements of set cement for gas storage, and provide guidance to cement slurry design.

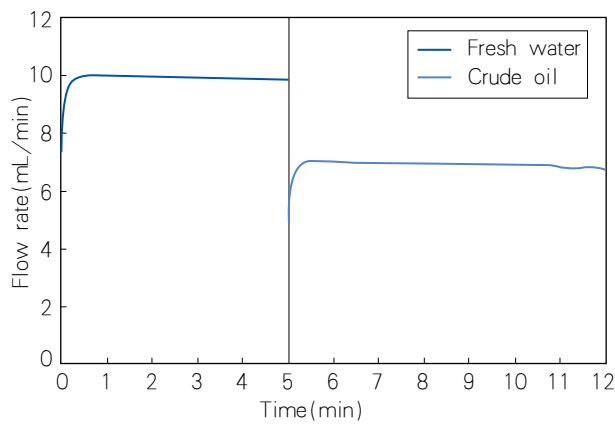
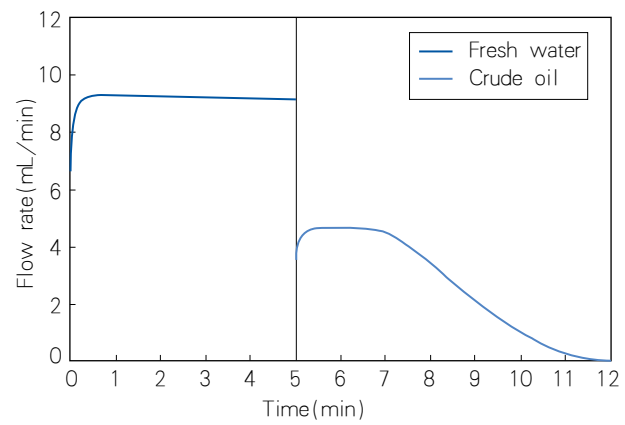
Elastic cement BCE-310S elastic toughened material has been developed. It increases the deformation capacity of set cement under the equivalent stress state, has low Young's modulus and high Poisson's ratio, and keeps sealing integrity under the action of alternating stress. The applicable temperature is 30~150°C

self-healing cement BCY-200S self-healing agent has been developed. When encountering oil and gas, it is of adsorption swelling to block cement ring fractures, function in self-healing and prevent fluids from further channeling. The applicable temperature is 30~150 °C . The self-healing cement is applicable to cementing operations in oil and gas wells and gas storage wells, effectively prevents wellhead belching and eliminates annular pressure.





Self-healing action process schematic

Percolation after conventional set cement
generates micro-fracturesPercolation after the set cement mixed with 5% complexing
agent generates micro-fractures

Gas storage cementing technology including salt cavern type gas storage cementing technology and depletion type gas storage cementing technology.

3

TYPICAL CASES

3.1 Deep well cementing technology used to solve high temperature small-clearance cementing problem in Dagang Huanghua sag

Well XG1 is a key risk exploration well in Xingang buried hill structure belt in Huanghua sag. A $\phi 152.4\text{mm}$ bit was used for the fifth spudding. $\phi 127\text{mm}$ liner was run to 6714m and the hanger location was at 6246m. The annular clearance in this interval was small (only 3.42mm at the hanger position), so that circulating displacement was limited and downhole settled sands were not carried out easily. The bottom hole static temperature reached 190°C . With regard to the above difficulties, before cementing operation, drilling fluid was adjusted and drifting measures were taken. To improve displacement efficiency, a prepad fluid system was introduced, and the prepad fluid turbulent contact time was $\geq 5\text{min}$ as guaranteed. BCR-300L high-temperature cement slurry system was adopted, thus solving high temperature problem. Reasonable displacement for cementing and displacement was used in cementing operations. Cementing operations were favorable. Logging shows good cementing quality.



3.2 The natural gas well cementing technology provides a powerful support to accelerating natural gas industrial base construction in Sichuan and Chongqing

Well LG62 is a preparatory well on Longgang structure of Yilong to Pingchang structure belt in Chuanbei depression in Sichuan basin. A $\phi 190.5\text{mm}$ bit was used for the fifth speeding, with the TD of 6353.00m. $\phi 168.3\text{mm}$ casing was run to seal off the interval 3400.00~6353.00m. The open hole section of the well was long and lost circulation and gas channeling risks coexisted. There was a large section of gypsum salt formations, easily leading to hole diameter shrinkage and affecting casing



lowering. The annular clearance was small, and cuttings were not removed easily. The bottom hole temperature was high and temperature range was large. As required, cement slurry should prevent channeling and meet the needs of large temperature difference. With regard to the above difficulties, the BHA with simulated casing rigidity was used to carry out repeated drifting and ensure safe casing running. A high-performance washing type prepad fluid system was optimized to prevent mutual pollution of contact fluids. Latex anti-channeling agents were used to increase anti-channeling capacity. A large temperature difference retarder was optimized to ensure set cement strength developed at the hanger location. Operations were favorable. CBL shows 83.7% percent of pass and 49.5% high quality ratio. After commissioning, the well has obtained $98.22 \times 10^4 \text{ m}^3$ daily industrial gas flow and its AOF has reached $759.18 \times 10^4 \text{ m}^3$.

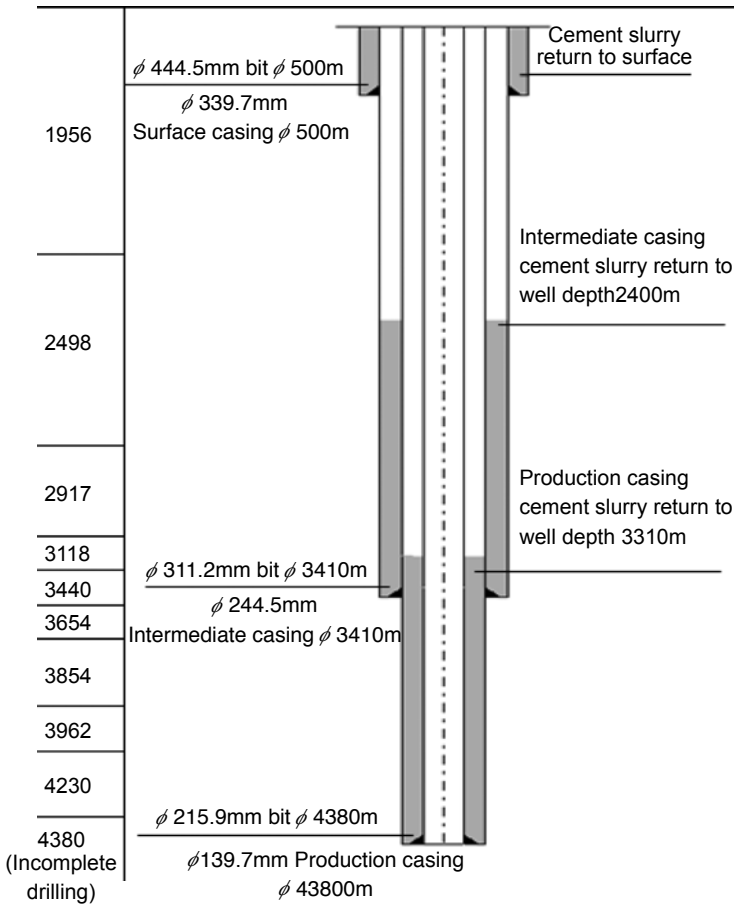
3.3 Solution to the cementing problem with a well containing high CO_2 content in Songliao basin using the sour gas reservoir cementing technology

Well CS10 is located in Xinli volcanic rock top surface structure in Qian'an sag belt of Changling fault depression in Songliao basin. $\phi 139.7\text{mm}$ production casing was run to 5610m for the fourth spudding. The formations in the cemented section contained high CO_2 content (over 90%). There were many target formations, pressure was complex, and gas channeling and leakage occurred easily. The static bottom hole temperature reached 194°C . Before cementing of the well, a pressure test was performed, and formation pressure and leak zones were determined. Two-stage two-consolidation cementing technology was adopted (stage collar location 2900m). The BCE-750S two-consolidation corrosion-resistant cement slurry system of 1.82g/cm^3 was used in stage I cementing. The high strength low density cement slurry with the lead slurry density of 1.60g/cm^3 was used in stage II cementing. The high quality ratio of cementing of the cemented section reached 85%. Since the well was put into production, no anomaly has occurred for five years.



3.4 Successful application of the leak well cementing technology in cementing operations in an easily leaked well in Jinlong-2 block in Junggar basin

Well J219 is located in well Jinlong-2 block in the east slope belt of Zhongguai bulge in the west uplift of Junggar basin, with the mid-completion depth of 3400m and the intermediate casing setting depth of 3397m. The safe density window of the cemented section of the well was narrow (around 0.2g/cm³), and there were high leakage risks during casing running and cementing. The three-pressure prediction technology was used. After drifting to bottom hole, weighted drilling fluid was pumped to simulate the fluid column pressure in cementing process and ensure cementing operation safety. Plugging type washing fluid was used to ensure bottom hole safety while improving displacement efficiency. Dual-density dual-consolidation cement slurry was used in cementing; the tail slurry was 1.90g/cm³ latex cement slurry, and the lead slurry was low density and high strength cement slurry to ensure reasonable annular fluid column pressure. The best operation parameters were determined with simulation software. Operations were favorable and no leakage occurred. The 72 hours CBL shows that the whole cemented section has high quality.



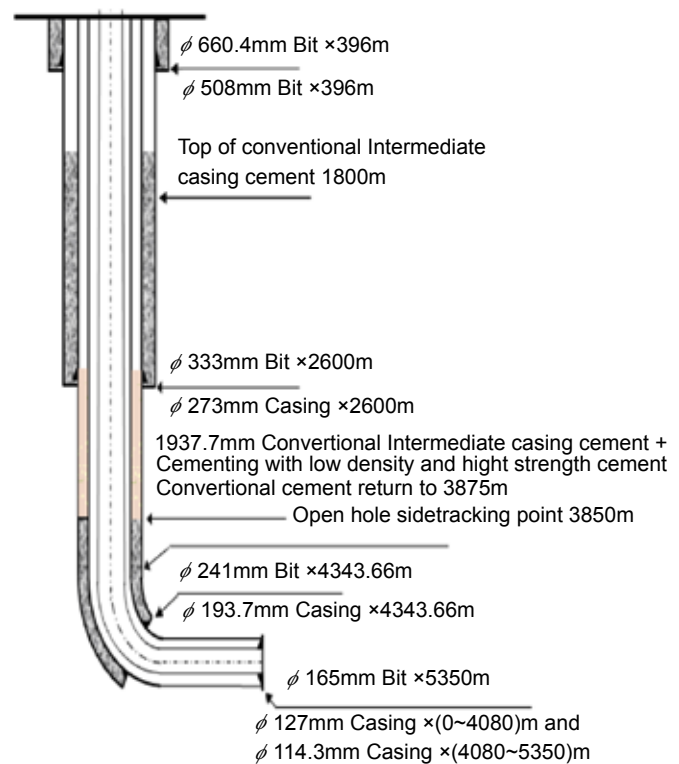
3.5 Improvement of the cementing quality of Kenkiyak subsalt reservoir in Kazakhstan with the salt gypsum cementing technology

Kenneyak reservoir is located in the structural belt in the east margin of the Caspian basin in Kazakhstan and belongs to Carboniferous reservoir structure, with the buried depth of around 4500m. There is a large section of 3000m thick salt gypsum formation, with the fracture pressure coefficient of 2.0 and the formation pressure coefficient of 1.94. 1.98g/cm³ saturated brine drilling fluid was used in drilling, its viscosity was high, and displacement was difficult. The density window was narrow, aftereffect was active, and blowout and leakage occurred easily. There was hidden trouble of annular pressure after cementing. 1.98g/cm³ weighted spacer fluid system and 2.01g/cm³ saturated brine latex cement slurry system were used in cementing in this block. Operations were favorable. The high quality ratio of cementing quality of the cemented section is over 70%, and the cementing problems such as a large section of salt gypsum formations and gas channeling have been solved effectively.



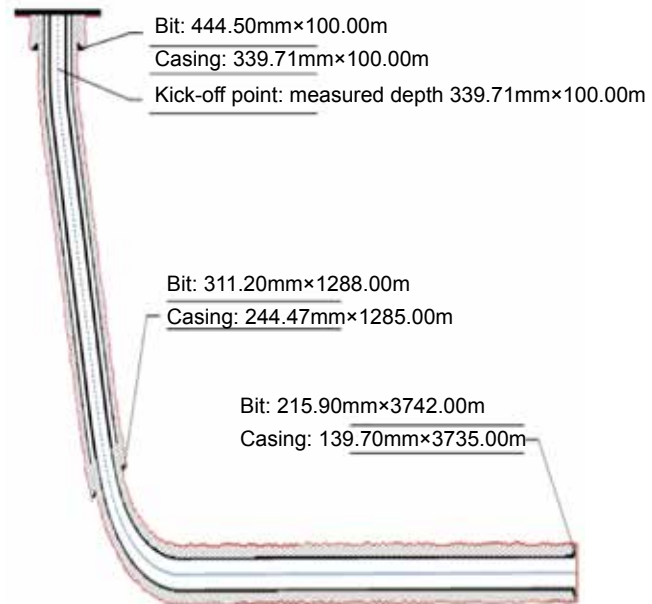
3.6 Application of the horizontal well cementing technology in tight sandstone oil and gas development to meet the needs of subsequent reservoir stimulation

Well J4H is a tight sandstone gas horizontal well in Shanshan arc, Taibei sag, Tuha basin and also a key demonstration well of national tight sandstone gas project. For the fourth spudding, the TD was 5350m, the vertical depth 4331m, the horizontal section length 1005m, the hole diameter 165mm, and the casing size in the horizontal section 114.3mm. Emulsified crude oil poly-sulfonated drilling fluid system (containing 5% oil) was used to drill the horizontal section. The target formation was Lower Jurassic Sangonghe Fm. The well was completed using the method of fracturing sliding sleeve and cementing. The well was fractured in ten sections and put into production, with the pressure of 80MPa. A formation leak pressure



test of the well was performed and it was drifted with the original drill string. Each piece of casing was fitted with a centralized in the horizontal section. Before cementing, the viscosity of the drilling fluid was reduced. 10m³ BCS-010L oil washing fluid, 16m³ low density and high strength lead slurry of 1.50g/cm³ and 18m³ high performance latex tail slurry were pumped. Brine was injected for displacement in the upper interval. During displacement, fresh water was injected for displacement in the horizontal section; in addition, dual-consolidation latex cement slurry was used and returned at a time to successfully seal off the interval 2900~5350m. The wellhead pressure and return displacement were normal and no borehole wall instability problem occurred during field cementing. The wellhead pressure was stable, the formation fracture starting pressure was 80MPa, and the extension fracture pressure reached 60MPa in the late fracturing operation process.

Well GP28-21 is located in Yishan slope in Ordos basin. A ϕ 215.9mm bit was used for the third spudding, with the TD of 3765m, the vertical depth of 1490.88m and the horizontal section length of 2006m. ϕ 139.7mm casing was run to seal off the whole well. The ratio of the horizontal displacement to the vertical depth of the well reached 1.70 and it was difficult to run casing. The horizontal section was long, it was difficult to clean cuttings beds, and casing centralizing degree and displacement efficiency were not easily guaranteed. Advanced water injection had high requirements for anti-channeling property of slurry. Multistage perforation and fracturing had high requirements for cement ring integrity. With regard to the above difficulties, the drifting method of combining the original BHA with the BHA with simulated casing rigidity was used, and the casing lowering technology of floating collars and installing a rigid roller centralizer on two pieces of casing was adopted. Downhole drilling fluid was timely circulated and settled sands were removed in real time during drifting and casing running. High-efficiency washing fluid was used to improve interface cementation. Toughened anti-channeling cement slurry system was used below 1400m. Operations were favorable. The cementation quality of the horizontal section has reached the anticipated target. 18 sections and 66 clusters of fracturing were completed successively in the late stage. Both the simulation section number and the stimulation cluster number in a single well have reached the maximum using the same technology in China. The average daily oil production of the well was 25.5t in the first month as of commissioning date, thus creating the record of the maximum production of a single tight oil horizontal well in Ordos basin.



3.7 The gas storage cementing technology has guaranteed the cementing quality of Shuang-6 depletion type gas storage well in Liaohe basin

Shuang-6 underground gas storage is located in Shuangtaizi fault anticline belt of the west sag in Liaohe basin and belongs to depletion type gas storage. The reservoir pressure coefficient was low (0.2~0.4) and leakage occurred easily. $\phi 244.5\text{mm}$ intermediate casing was run to 2600m, with cement slurry returned to surface. Continuous two-stage cementing method was used. The method of 177.8mm casing and composite screen was used in the target formation. According to the above description, the dual-density cement slurry system including the latex toughened anti-channeling cement slurry of conventional density combining high strength and low density cement slurry of 1.35g/cm^3 was used to increase anti-gas channeling capacity, reduce cement slurry fluid column pressure and prevent cement slurry leakage during operations. Through cement ring integrity evaluation, the latex toughened anti-channeling cement slurry can bear 82MPa casing internal pressure at most in the gas storage operation environment, which is higher than the lowest casing internal pressure 28.8MPa needing be borne by the cement ring of the gas storage. Operations were safe and favorable. Logging shows that the cementing quality of both intermediate casing and production casing is high quality.



4 SCIENTIFIC RESEARCH EQUIPMENT

CNPC is fitted with drilling engineering key laboratory and cementing technology research office, including 5 major functional laboratories such as cementing basic theory and technology, cement additive, special cement, chemical synthesis and comprehensive performance evaluation. Laboratories have totally 140 pieces (sets) of testing instruments and 5 sets of self-developed equipment including

advanced and complete set cement mechanical property analyzers, static gelling strength analyzers, gas channeling evaluation instruments, etc. and are provided with the comprehensive capacity of performance simulation testing and evaluation of various oil well cements as well as R&D and evaluation of additives.



Set cement mechanical property analyzer



Static gelling strength analyzer



Set cement corrosion tester



Laboratory

5 QUALIFICATION STANDARDS

CNPC has passed API Q1 quality management system certification and Great Wall quality management system certification, formulated over 30 technical standards and obtained 13 national, provincial and ministerial key new products. CNPC has obtained 10 national patents.



Patents

No.	Patent name	Patent No.	Type
1	Spacer fluid for oil well cementing	200610089273.3	Invention patent
2	A retarder for oil well cement	200710120344.6	Invention patent
3	A synthetic method for special modified SBR latex for cement slurry in oil and gas fields	200810167189.8	Invention patent
4	A fluid loss additive for oil well cement slurry	200810226689.4	Invention patent
5	A high temperature retarder for oil well cement	200910086737.9	Invention patent
6	A cement slurry system applicable to large temperature difference cementing	201010620812.8	Invention patent
7	An oil well cement retarder and its preparation method	201010214915.4	Invention patent
8	A medium temperature retarder for oil well cement	201010251853.4	Invention patent
9	A CO ₂ corrosion resistant cement for cementing	201110297635.9	Invention patent
10	Cement slurry leakage stoppage simulation test equipment	ZI200520119105.5	Utility model patent

6

EXPERT TEAM



Qu Jiansheng Professor level senior engineer. He is mainly engaged in the study and application of complex natural gas well cementing technologies. He mainly studies HTHP natural gas well cementing technologies. He has obtained 1 national science and technology advance prize, 9 provincial and ministerial science and technology advance prizes and 4 patents. Over 20 papers written by him have been published.
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