# Chapter 6
# Research and Application of Key Drilling Technologies in Nappe Tectonics of Xinjiang Region

**Jifei Cao, Deyong Zou, Cheng Li, Zhe Huang, Jianxiang Sun, and Weiqiang Zhang**

**Abstract** The nappe tectonics in Xinjiang had been affected by old stratum, complex pressure system, strong heterogeneity. Drilling engineering is faced with problems such as low rate of penetration (ROP), frequent leakage, and long drilling period. According to the theoretical analysis, laboratory and field experiments, a series of key drilling technologies have been formed with the core technologies of optimized design for nappe tectonics drilling engineering, ROP improving for high steep and hard formation, fracture formation leakage prevention and plugging while drilling, and gypsum salt formation safe drilling, and had been successfully applied in the drilling of KPN-1 well, the first deep exploration well in Xinjiang nappe tectonics zone. Based on 3D seismic data, formation lithology data, and adjacent wells data, the prediction method of complex formation pressure and the wellbore design principle for nappe tectonics zone are established. The application of the deviation control technology in drilling high steep and hard formation increased the ROP of KPN-1 well by 30%, and the deviation angle is controlled within 2°. The application of personalized bit with special-shaped cutter in Yingshan Group limestone formation increased the ROP by 90%, and the footage of single bit in lower Qiulitag Group silty dolomite formation increased by 30%. The plugging technology could effectively solve the fracture formation leakage in long well section. The saturated salt water drilling fluid system has good anti-pollution ability and good wellbore instability. These technologies are instructive for the drilling engineering in the hard formation of Xinjiang nappe tectonics zone.

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## 6.1 Introduction

Xinjiang region is rich in oil and gas resources. In recent years, several major discoveries have been made in the exploration and development of deep Cambrian here, which further promoted the exploration and development of Cambrian oil and gas resources in the Tarim Basin in Xinjiang. In 2019, KP-1 well obtained high productivity of industrial gas flow in the middle and lower Cambrian, which confirmed the good resource exploration potential and oil and gas accumulation conditions of the Keping fault uplift belt, and opened up a new oil and gas exploration position for the Tarim Basin [1].

The Keping fault uplift belt is located in the northwest margin of the Tarim basin, and is a large fault uplift in the multi-row fault structural domain running from the north to the east [2]. The south area of Keping is located in the Aheqi high of the Keping fault uplift belt, where the east–west to northeast thrust nappe structure is developed. Affected by multi-stage tectonic movement, the regional strata are old, the pressure system is complex, the plane and vertical heterogeneity is strong, and the reference data of adjacent wells are lacking. Moreover, it is difficult to predict the engineering geological characteristics. According to the technologies of optimized design in nappe tectonics drilling engineering, ROP improving in high steep and hard formation, fracture formation leakage prevention and plugging while drilling, and gypsum salt formation safety drilling, a series of key drilling technologies suitable for the south Keping have been formed. Then, the construction of the first deep exploration well KPN-1 in this block has been completed based on these technologies, providing engineering technical support for the exploration and development of oil and gas resources in the south Keping area.

## 6.2 Technical Difficulties of Drilling Engineering in South Keping Area

### *6.2.1 Engineering Geological Characteristics of South Keping Area*

Affected by the violent tectonic movement, the thrust fault nappe tectonics of Ordovician and Cambrian strata are above the Cenozoic, and the upper stratum dip is predicted to be as high as 30–50°. Silurian, Ordovician (upper sand-mudstone), Cambrian (lower Churitag Formation, Awatage Formation, Shairic Formation, Wusonger Formation, Sholbluk Formation, Yuertus Formation), Sinian (Chigbluk

Formation) are encountered in this area from top to bottom [3]. The middle and lower Ordovician and upper Cambrian strata are dominated by limestone and dolomite, while the lower Cambrian strata are dominated by dolomitic gypsum. The formation pressure above the nappe is mainly atmospheric pressure, and the local formation pressure of the gypsum salt rock section of the Avatag Formation and Shairik Formation below the nappe is as high as 1.5–1.9. It can be seen from the lithology and pressure system characteristics of the formations in the region that the limestone and dolomite formations with high and steep structure and large dip angle are hard and have poor drillability, and the fractured formation in long well section has a great impact on safe drilling operation.

### *6.2.2 Analysis of Technical Difficulties in Drilling Engineering*

Combined with the engineering geological characteristics of the south area of Keping and the actual drilling data of exploration wells in adjacent blocks, the main technical difficulties in deep well drilling engineering are as follows:

(1) The formation lithology and pressure system of nappe structure are complex, leading to high drilling risk. Under the influence of the multi-stage structures, the pressure system is complex, and the gypsum salt layer develops high pressure. Moreover, the fractured formations such as limestone and dolomite are prone to leakage, and there are few geological data available for reference. The wellbore integrity has high requirements on the wellbore design and safe drilling technology.
(2) The formation with high and steep structures is hard and have large dip angle, leading to the poor ROP. The drillability of limestone and dolomite formations such as Yingshan Formation, Penglaiba Formation and Lower Qiulitag Formation are all more than grade 6. These formations are hard and brittle, and difficult to be drilled by conventional bits, which could lead to serious cutter broken. The ROP in the adjacent wells are $<1.5$ m/h.
(3) The formation fractures in the long well section are developed, and the problem of lost circulation is prominent. Fractured leakage of limestone and dolomite is characterized by randomness and repeatability, and the amount of leakage is large, which seriously affects the drilling efficiency. The total number of leakage happening in KP-1 well and KT-1 well of the adjacent block reaches 20–30 times, and the cumulative leakage amount is 3000 $m^3$.
(4) The gypsum salt layer is deeply buried and develops abnormally high pressure, which is easy to cause overflow and sticking. The development of gypsum salt layer in the Awatage Formation to Wusonger Formation of Cambrian locally contains high-pressure salt water layers, which are prone to overflow, well leakage and other problems. The overflow happenned in KT-1 well when it was drilled to 3484.56 m (density 1.6 $g/cm^3$), and the lost circulation occurred during

the well killing process, and the pipe stuck happenned during pressure-bearing plugging, leading to the time loss up to 50 d.

## 6.3 Optimized Design Technology for Nappe Tectonics Drilling Engineering

### *6.3.1 Prediction and Analysis of Formation Pressure Based on Well Seismic Information*

Based on the regional 3D seismic data and the distribution characteristics of formation lithology, the prediction method of complex formation pressure in south Keping is established, combined with the logging data of similar formations in adjacent blocks. The existing mature methods are used to calculate the pore pressure of sand-mudstone formation, and the prediction and analysis of fracture pressure and collapse pressure are carried out according to the leak off test data and rock physical parameters of adjacent blocks. According to the special properties of carbonate formation and considering the influence of carbonate porous media, the abnormal response laws of fractures and dissolved holes to acoustic velocity are studied and analyzed by the artificial core technology, and the influence coefficient of fracture characteristics of carbonate formation on acoustic velocity is determined. On this basis, the calculation and analysis of pore pressure of carbonate rock and gypsum salt formation are carried out by using Phillips method, and finally the three-pressure profiles of different formations in the south Keping area are obtained, as shown in Table 6.1.

### *6.3.2 Optimization Design of Wellbore Structure for South Keping Area*

According to the structural characteristics of the nappe, the uncertainty of geological prediction, and the requirements of drilling objectives in the south Keping area, the well structure design principles in this area are studied and determined, namely, one sealing point and two necessary sealing points. The sealing point is required to seal the upper geological fault and the first set of repeated strata, and the fault gypsum and salt layer shall not be drilled, which should be constructed together with the lower stratum. The first necessary sealing point is located at the top of the Cambrian Avatage Formation, which isolates the gypsum salt layer in the Avatage Formation—Wusonger Formation, to prevent the upper low pressure formation from leakage or differential pressure sticking during high-density drilling in the gypsum salt layer. The second necessary sealing point is located at the top of the Sholbluk formation. Considering that the Cambrian Sholbluk formation is a fracture-porosity gray dolomite, which is the main target layer of this well, the strata above the Sholbluk

**Table 6.1** Pressure coefficients of different horizons in Keping area

| Geological stratification | Vertical depth/m | Caving pressure/(g/cm$^3$) | Pore pressure/(g/cm$^3$) | Fracture pressure/(g/cm$^3$) |
|---|---|---|---|---|
| Devonian system—upper Silurian system | 0–300 | 0.9–1.00 | 1–1.02 | 1.95–1.98 |
| Silurian system—upper Cambrian system | 300–2500 | 0.8–1.08 | 1–1.06 | 1.98–2.03 |
| Nappe fault | 2500–3001 | 0.9–1.02 | 1–1.07 | 2.01–2.03 |
| Fault—upper Ordovician system | 3001–3580 | 1.02–1.15 | 1.02–1.08 | 2.03–2.05 |
| Lower and middle Ordovician system—lower Churitage formation | 3580–4791 | 1.07–1.16 | 1.07–1.21 | 2.07–2.11 |
| Cambrian Avatag formation—Wusonger formation | 4791–5102 | 1.16–1.25 | 1.42–1.65 | 2.10–2.11 |
| Lower Cambrian system—Sinian system | 5102–5600 | 1.08–1.2 | 1.26–1.35 | 2.11–2.15 |

Formation should be isolate, which is conducive to the discovery and protection of reservoirs [4]. Based on the above design principles, the appropriate well structure of KPN-1 well is finally determined, as shown in Table 6.2), and an alternative design scheme is developed to ensure the realization of the drilling objectives of the well.

### *6.3.3 Design of Casing String for Gypsum Salt Formation of Nappe Structure*

In combination with the requirements of special drilling and sealing, safe drilling, and wellbore integrity in the gypsum and salt formations, the overlying strata pressure is used instead of the formation pore pressure to carry out the design check of the casing string against external collapse, based on the investigation and analysis of the selection of casing in the gypsum and salt formations in the Tarim Basin, to optimized the casing which could meet the maximum internal pressure and external collapse requirements. Based on the calculation and analysis of the uniaxial and triaxial safety factors of the casing string under different working conditions (full of gas in the casing, full emptying and casing running), the casing model (outer diameter 184.15 mm, steel grade P125TS, wall thickness 15.83 mm) suitable for safe drilling in the gypsum salt formation of south Keping is optimized.

**Table 6.2** Well structure design of KPN-1

| Structures | Wellbore size/mm | Well depth/m | Casing | | Cement top/m | Engineering purposes |
|---|---|---|---|---|---|---|
| | | | Outer diameter/mm | depth/m | | |
| Conductor casing | | 30 | 720 | 30 | | |
| First spud | 660.4 | 300 | 508 | 300 | Ground | Wellhead construction |
| Second spud | 444.5 | 3001 | 339.7 | 3000 | Ground | Isolate the geological fault above and the strata above Cambrian that are prone to leakage and collapse, without drilling the gypsum rock and gypsum salt rock |
| Third spud | 311.2 | 4791 | 244.5 | 4790 | Ground | Isolate the formation above the salt gypsum layer of the Awatage Formation |
| Forth spud | 215.9 | 5202 | 184.15 | 5200 | Casing shoe 4640 | Confirm that the gypsum salt rock formation of Wusonger Formation is dilled through, and the gypsum salt rock and high pressure salt water layer in Awatage-Wusonger Formation are isolated |
| Fifth spud | 149.2 | 5600 | 114.3 | 5597 | Casing shoe 4790 | Drilling to completion depth |

## 6.4 ROP Improving Technology for High Steep and Hard Formation

### *6.4.1 Deviation Control Technology in Drilling High Steep and Hard Formation*

Limited by geological factors and borehole quality requirements, the ROP could not be improved effectively. Under the influence of geological movements, the upper stratum in the south Keping area has a large dip angle. How to effectively realize the deviation control is the problem that must be solved to provide guarantee for the smooth construction of subsequent well sections.

Based on the regional lithology data, the natural deflection characteristic model of high and steep structural strata is studied and established to guide the optimization of drilling methods and drilling parameters. Taking the well section of 480–2500 m as an example, the vertical drilling technology had a good performance, and the ROP increased by 30% compared with the same layer of KT-1 well, with the well deviation controlled within 2°. In order to further cutting the cost of the application of deviation control technology, the geological information was analyzed in time during the actual drilling process. Taking the well section of 2830–3086 m as an example, the formation dip angle was predicted <20°, thus the drilling tools assembly was optimized to be the pre-bending dynamic vertical drilling tools assembly by using the small degree bending screw, which includes φ444.5 mm drill bit, (0.75–1)° single bending screw without centralizer, one φ228.6 mm drill collar, φ436–440 mm centralizer, etc. Taking the advantage of its whirling feature to control deviation, the well deviation decreases from 3° to 1.2° during the actual drilling process. In the meanwhile, the screw drilling tool can provide enough rock-breaking torque to further realize anti-deviation and fast drilling [5, 6].

### *6.4.2 Development of Personalized Drill Bit for Limestone and Dolomite*

Based on the regional seismic data, logging information, and outcrop core, the laboratory experiment of rock mechanical characteristics and mineral composition analysis of key layers in the south Keping area has been completed. The limestone and dolomite below the Ordovician Yingshan Formation has a drillability of more than 6 levels hard and brittle features. The Penglaiba Formation and Lower Qiulitage Formation have high dolomite content, and some layers contain siliceous, thus the drill bit should have good performance on penetrating, impact resistance and stability.

**The PDC drill bit applied in hard limestone stratum**. The limestone stratum is difficult to be drilled due to its hard feature, which will lead to poor working stability of the drill bit or even damaged, low ROP, and low footage of single drill bit. In order to improve the utilization rate of rock breaking energy, the research and development of PDC drill bit for limestone stratum is carried out based on the combination rock breaking theory and method of "pre crushing+stress release+shear" [7–9]. In order to improve the impact resistance and stability of the drill bit, the φ16 mm cutter with high impact resistance is selected, and the parabolic structure of the bit crown is optimized. Moreover, the drill bit structure design of thick plane cutter+conical cutter is adopted, which because that the conical cutter could reduce the rock breaking threshold, and stabilize the working state of the drill bit. The high-performance PDC bit developed according to the above technical means had been successfully applied in the south Keping area (Fig. 6.1). Taking the limestone formation of Yingshan Formation of 3530–3985 m as an example, the footage of a single drill bit is 455 m, and the average ROP is 4.5 m/h, which is 90% higher than that of KT-1 well at the same layer.

**Cone-PDC mixed drill bit for th dolomite stratum**. The drillability of the dolomite stratum in the Ordovician to Cambrian is about 7, and some layers reach 8. In order to further improve the rock breaking efficiency of dolomite rock, the shape and rock

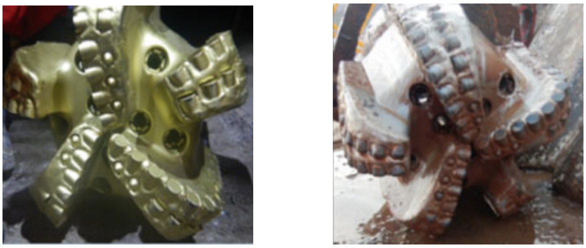

**Fig. 6.1** Application effect of PDC bit in hard limestone formation

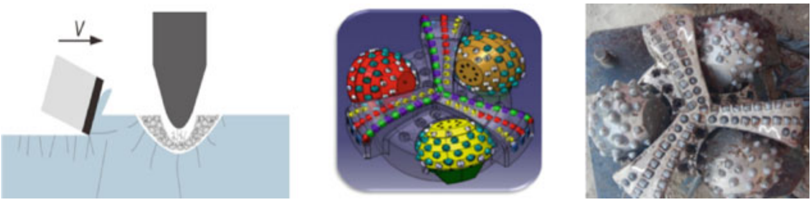


**Fig. 6.2** Cone PDC hybrid bit for dolomite formation

breaking mode of cutter were optimized and analyzed based on numerical simulation and laboratory experiment, and a cone-PDC mixed drill bit was developed, as shown in Fig. 6.2. This type of drill bit has both rock-breaking characteristic of cone drill bit and PDC drill bit. During drilling, the application of the cone could effectively reduce the difficulty of PDC cutter. Moreover, the φ16 mm axe cutter with stronger penetration ability is selected to improve the penetration ability of the drill bit. In order to protect the centre area of drill bit, the triangular cutter is used to improve the impact resistance and wear resistance of the drill bit. The design of rear conical cutter could improve the stability of the drill bit and effectively extends its life. Taking the 2207–2360 m lower Churitag Formation silty dolomite stratum as an example, the footage of a single drill bit is 30% higher than that of the adjacent well.

## 6.5 Fracture Formation Leakage Prevention and Plugging While Drilling

The leakage modes in the south Keping area are mainly of fracture type and hole type. The leakage formation is complex which is difficult to be plug, and the repeated leakage is easy to occur. In view of the above technical problems, the multi-element collaborative leak prevention and plugging system and the elastic hole-mesh leak prevention and plugging system have been developed, effectively solving the technical problems of leakage in the south Keping area, and improving the success rate of primary leak plugging.

### *6.5.1 Multi-element Collaborative Leak Prevention and Plugging System*

This technology is applicable to the formation with low leakage rate and small loss. The plugging agent can effectively seal the fractures depended on the multiple synergistic actions. The rigid plugging agent is used as the basic framework, and the granular material is used for primary sealing. Moreover, the flexible particles can plug the small fractures, and the ultra-fine material enters the remaining cracks, forming a relatively solid sealing layer. This system uses rigid plugging agent as the main agent, and cooperates with the selected suspension stabilizer, plugging fiber, filling particles, and sheet materials. In order to evaluate and analyze the performance of the system under different dosage of treatment agent, the laboratory experiments of 2 and 4 mm seam plates under 80, 100, and 120 °C environment were carried out, as shown in Tables 6.3 and 6.4.

**Table 6.3** Plugging performance test of 2 mm seam width

| No. | Rigid plugging agent A/% | Rigid plugging agent B/% | 80 °C | | 100 °C | | 120 °C | |
|---|---|---|---|---|---|---|---|---|
| | | | Leakage/mL | Pressure resisting capability/MPa | Leakage/mL | Pressure resisting capability/MPa | Leakage/mL | Pressure resisting capability/MPa |
| 1 | 0 | 10 | 411 | 7.5 | 420 | 7.1 | 518 | 6.6 |
| 2 | 0 | 10 | 385 | 9.4 | 392 | 9.8 | 426 | 10.9 |
| 3 | 4 | 6 | 258 | 16.4 | 267 | 15.5 | 272 | 15.8 |
| 4 | 4 | 6 | 182 | 17.9 | 189 | 18.5 | 195 | 18.3 |
| 5 | 6 | 4 | 136 | 21.2 | 122 | 22.4 | 128 | 20.8 |
| 6 | 6 | 4 | 87 | 23.7 | 82 | 24.4 | 90 | 21.1 |

**Table 6.4** Plugging performance test of 4 mm seam width

| No. | Rigid plugging agent A/% | Rigid plugging agent B/% | 80 °C | | 100 °C | | 120 °C | |
|---|---|---|---|---|---|---|---|---|
| | | | Leakage/mL | Pressure resisting capability/MPa | Leakage/mL | Pressure resisting capability/MPa | Leakage/mL | Pressure resisting capability/MPa |
| 1 | 4 | 6 | 327 | 12.5 | 338 | 12.1 | 395 | 11.4 |
| 2 | 4 | 6 | 315 | 13.4 | 324 | 13.1 | 386 | 12.1 |
| 3 | 4 | 10 | 310 | 15.6 | 318 | 16.3 | 346 | 15.9 |
| 4 | 4 | 10 | 297 | 17.9 | 306 | 17.6 | 368 | 17.2 |
| 5 | 8 | 6 | 154 | 20.8 | 163 | 21.4 | 174 | 20.1 |
| 6 | 8 | 6 | 118 | 21.3 | 120 | 22.6 | 125 | 21.8 |

As shown in Tables 6.3 and 6.4, in the experiment of 2 mm seam plate, under the premise that the dosage of two rigid plugging agents is maintained at 10%, the pressure bearing capacity when the dosage of rigid plugging agent A reaches 4% is higher than 15 MPa, and is higher than 20 MPa when reaches 6%. In the experiment of 4 mm seam plate, the pressure bearing capacity when the dosage of rigid plugging agent A reaches 8% and agent B reaches 6% are higher than 20 MPa. These results all could achieve good leak-proof and plugging effect on fractured formation. This technology had greatly improved the construction requirements of small size fracture formation in the KPN-1 well, and success rate of primary leak plugging is 100%.

### *6.5.2 Elastic Hole-Mesh Leak Prevention and Plugging System*

Aiming at the formation with large size cracks and serious hole-type leakage, a plugging system based on elastic hole-mesh material is developed. Under the effect of bottom hole pressure difference, the elastic hole-mesh material has the ability of self-adaptability. This material can play the role of skeleton support by forming a mesh structure at the fracture to turn the fracture into a hole, that could effectively reduces the permeability and leakage rate of the fracture sealing layer. At the same time, the elastic hole-mesh material can capture other types of plugging materials to form a three-dimensional plugging barrier, that could improve the retention capacity of plugging materials in fractures, and further improve the success rate of primary plugging [10, 11]. With the continuous accumulation of plugging materials, the sealing layer can bear more external loads, greatly improving the sealing pressure bearing capacity, as shown in Fig. 6.3.

Based on the elastic hole-mesh plugging materials, rigid particles, elastic particles, and fiber plugging materials, the laboratory long fracture plugging evaluation test is carried out. The basic recipe is: 5–6% mud+0.3– 0.5% polyanionic cellulose+4% GDJ-2+1% RDJ-2+3% GDJ-3+1% RDJ-3+3% GDJ-4+1% RDJ-4+2%

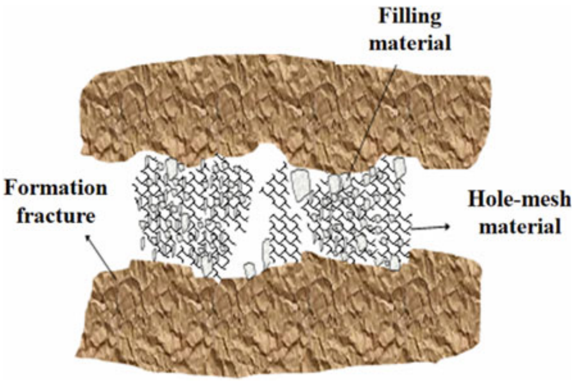


**Fig. 6.3** Schematic diagram for plugging of elastic hole network system

**Table 6.5** Plugging performance test of 8mm seam width

| No. | Recipe | Plugging area/mm | Pressure resisting capability/MPa | Leakage/mL |
|---|---|---|---|---|
| 1 | 0.4% EMM (5 mm × 5 mm × 5 mm)+bridging material | 940–970 | 5 | 310 |
| 2 | 0.8% EMM (5 mm × 5 mm × 5 mm)+bridging material | 895–935 | 6 | 265 |
| 3 | 1.2% EMM (5 mm × 5 mm × 5 mm)+bridging material | Whole sealing | / | / |
| 4 | 0.8% EMM (hole size 30 ppi)+bridging material | 895–935 | 6 | 265 |
| 5 | 0.8% EMM (hole size 50 ppi)+bridging material | 900–945 | 6 | 245 |
| 6 | 0.8% EMM (hole size 80 ppi)+bridging material | 895–950 | 6 | 220 |

GDJ-5+0.2% FDJ+0.8% EMM. As shown in Table 6.5, with the increase of the concentration of the elastic hole-mesh plugging material, the pressure bearing capacity can reach 6 MPa. With the decrease of pore size of plugging material, the plugging area and pressure bearing capacity are basically unchanged, and the leakage amount is reduced. In the KPN-1 well, the amount of elastic hole-mesh plugging material and other plugging material were optimized based on the actual leakage states. Finally, this system were applied for 10 times during the second and third spud in the fractured formation, and no re-leakage occurred. Thus, this technology could greatly improve the plugging efficiency of large size fractures.

## 6.6 Gypsum Salt Formation Safe Drilling Technology

The performance and density of drilling fluid system are important factors that affect the safe drilling of gypsum salt formations. In order to reasonably predict and analyze the creep rate of gypsum salt formation, relevant researches had been carried out based on theoretical analysis and laboratory experiments. It can be seen from Fig. 6.4 that the creep rate and dissolution rate of the gypsum salt layer depend on the density of the drilling fluid and the concentration of chloride ions. When they are balanced, the stability of the borehole wall of the gypsum salt layer can be guaranteed. According to the geological burial depth of the gypsum salt formation in the south Keping area, it is recommended that the chloride ion content of the drilling fluid should not be <100,000 mg/L and the density of the drilling fluid should not be <1.60 g/cm$^3$ to control the creep and dissolution rate of the gypsum salt.

On the basis of the above researches, a saturated brine drilling fluid system suitable for the gypsum and salt formation in the south Keping area has been developed, and

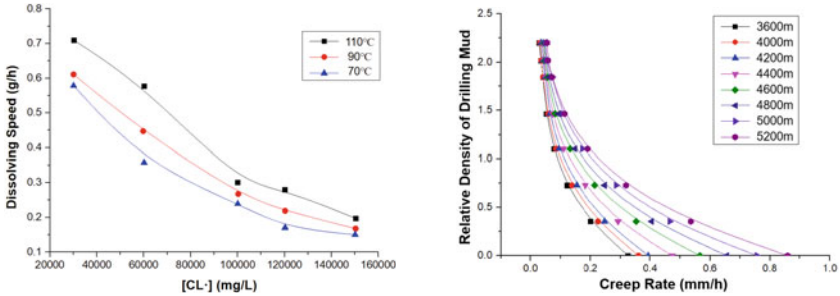


**Fig. 6.4** Analysis of dissolution and creep rate of gypsum salt formation

**Table 6.6** Aging experiment of undersaturated brine system

| $\rho$/ ($g \cdot cm^{-3}$) | Experiment conditions | AV/ (mPa · s) | PV/ (mPa · s) | YP/Pa | Gel/ ($Pa \cdot Pa^{-1}$) | FLAPI /mL | FLHTHP /mL |
|---|---|---|---|---|---|---|---|
| 1.70 | Before aging | 41 | 30.5 | 10.5 | 3/5 | 3.0 | 10.2 |
| | 120 °C/16 h | 44 | 32 | 12 | 3.5/6 | 3.8 | 11.0 |
| 1.85 | Before aging | 47 | 35 | 12 | 4/7 | 2.8 | 9.4 |
| | 120 °C/16 h | 52.5 | 38 | 14.5 | 4/8.5 | 3.0 | 10.2 |
| 2.05 | Before aging | 57 | 42 | 15 | 5/11 | 3.2 | 9.8 |
| | 120 °C/16 h | 61.5 | 45 | 16.5 | 6/12.5 | 3.6 | 10.8 |

the basic recipe is 3–4% bentonite + 0.4–0.5% caustic soda + 0.3–0.5% polyacrylamide potassium salt + 0.5–1% sulfonate copolymer fluid loss additive + 4–5% sulfonated phenolic resin + 2–3% branched phenolic resin + 5–7% asphalt resin compound + 0.5–1% organic silicon stabilizer + sodium chloride. As shown in Table 6.6, this system has good rheology, small filtration loss, and stable performance under different density conditions. The field application results in the KPN-1 well show that this system has the features of good anti-pollution ability and small well diameter expansion rate, and did not cause wellbore instability, which meets the requirements for safe drilling in the gypsum salt formation in the south Keping area [12].

## 6.7 Field Application and Analysis

The key drilling technologies for the south Keping area has been successfully applied in the KPN-1 well, which include the optimized design technology for nappe tectonics drilling engineering, ROP improving technology for high steep and hard formation, fracture formation leakage prevention and plugging while drilling technology, and gypsum salt formation safe drilling technology, and thes technologies had been optimized according to the actual states during drilling engineering. The total depth of KPN-1 well is 5385 m, and the wellbore quality meets the requirements of Party A. The casing strings in second spud were deformed under the influence of the objective factors such as sudden earthquake, that leading to the application of the standby wellbore structure plan to complete the subsequent drilling engineering after the casings were repaired successfully with own technology. The whole drilling cycle of this well was 629 d (the complex cycle caused by earthquake, epidemic, etc. accounted for 30%). The construction of KPN-1 well was successfully completed, which is the first deep exploration well in this block, and all geological data were obtained accurately, ensuring the exploration and development of regional oil and gas resources.

## 6.8 Conclusions and Recommendations

A series of key drilling technologies in the south Keping area has been studied and established, and the construction of the first deep exploration well in this block has been successfully completed, providing engineering and technical support for the exploration and development of regional oil and gas resources.

The technologies of multi-element collaborative leak prevention and plugging and the elastic hole-mesh leak prevention and plugging are continuously optimized and improved in the field application process, but the long well section and multipoint random loss have brought great impact on drilling engineering. Aiming at these problems, these technologies need further research to improve the adaptive ability and long-term plugging performance of plugging materials.

The resolution of seismic layer velocity to identify high pressure formation is low, and the existing technology cannot identify the change of formation pressure to be drilled in real time. It is recommended to strengthen the prediction and monitoring of pressure while drilling (seismic while drilling, etc.) for the subsequent construction of similar wells to provide the most effective basis for the optimization of drilling technology.

The exploration and development of Cambrian oil and gas resources in the Tarim Basin is the key breakthrough direction of the whole basin. The research and optimization of high-performance drill bit with special-shaped cutter, steady-state ROP improving tool, and low-cost vertical drilling tool are the most effective technologies for ROP improving in hard and difficult formations with high and steep structures.

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