EFFICIENT DEVELOPMENT OF KESHEN GAS FIELD

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China National Petroleum Corporation

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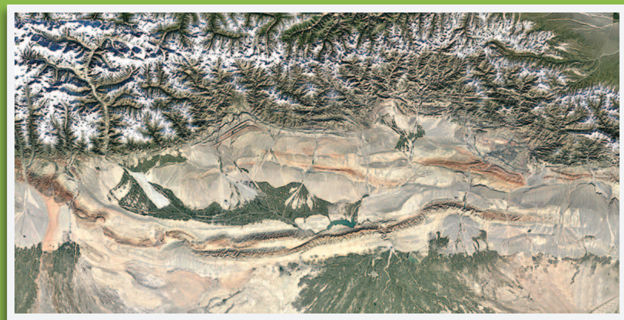
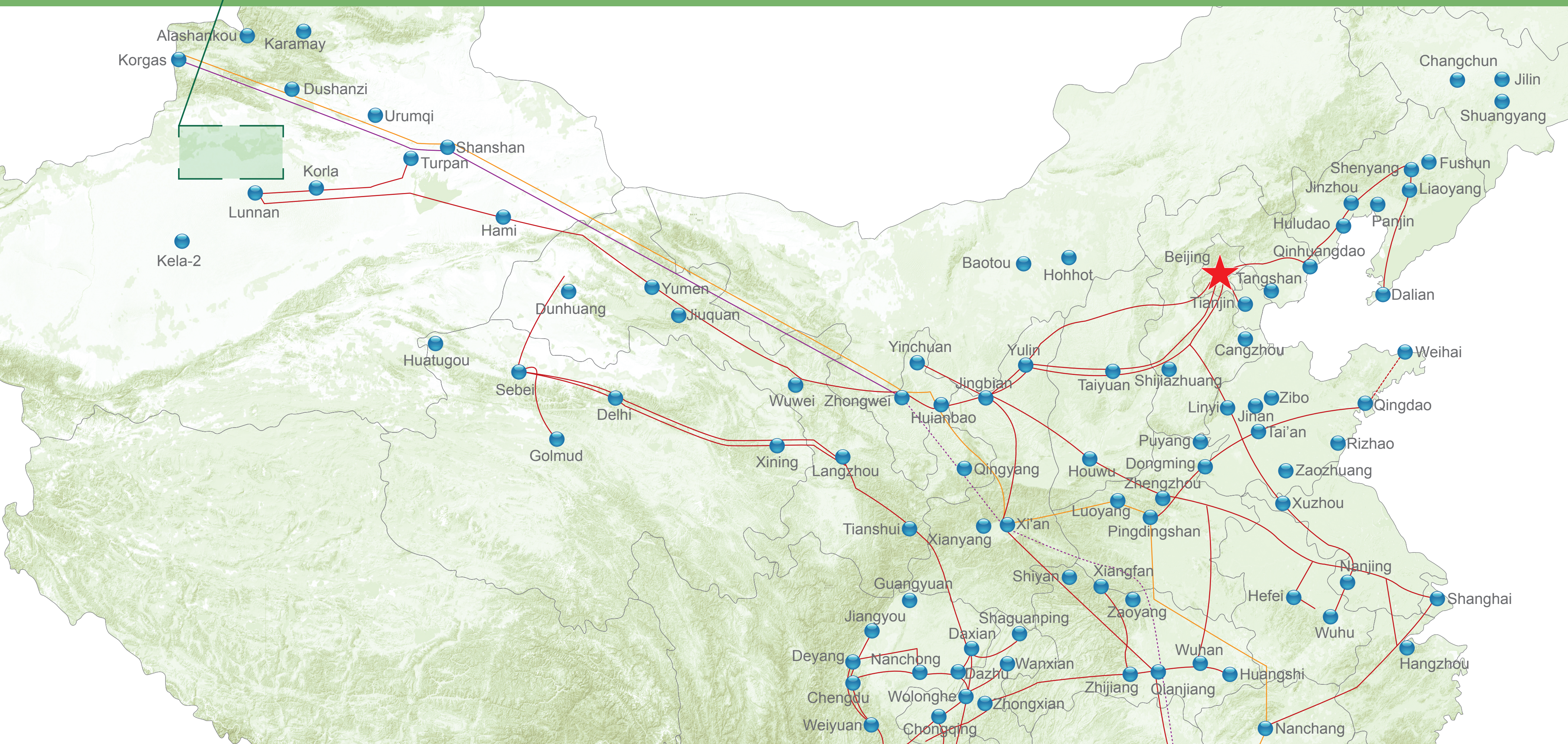


Keshen gas field is located in the mountainous Kelasu structural belt of the Tarim basin in China's Xinjiang Uygur Autonomous Region. Development of the gas field is highly challenging due to its ultra-deep, fractured tight sandstone reservoirs with extremely high pressure. Adopting an integrated exploration and development mode, CNPC built an annual capacity of 5bcm at Keshen gas field within seven years, and achieved excellent HSE performance with "zero pollution and zero injuries".



Geographic and Geological Characteristics

The surface of Keshen gas field is dominated by mountains and ravines without vegetation. The maximum relative relief can be 500m, and the maximum dip angle of outcrops is over 80 degrees. The imbricated gas reservoirs, with a burial depth of 6,500-8,000m, are covered by massive salt layers with a maximum thickness of 4,000m. And the overlying of the salt layers is an overthrust nappe, making the main structural part severely superposed.

Gas Reservoir Features

- Burial depth: 6,500-8,000m
- Temperature: 120-193°C
- Thickness: 300-650m
- Pressure: 116-128MPa
- Structure dip: 30-50°
- Porosity: 1.5-7.0%
- Permeability < 0.1mD

Challenges in Gas Field Development

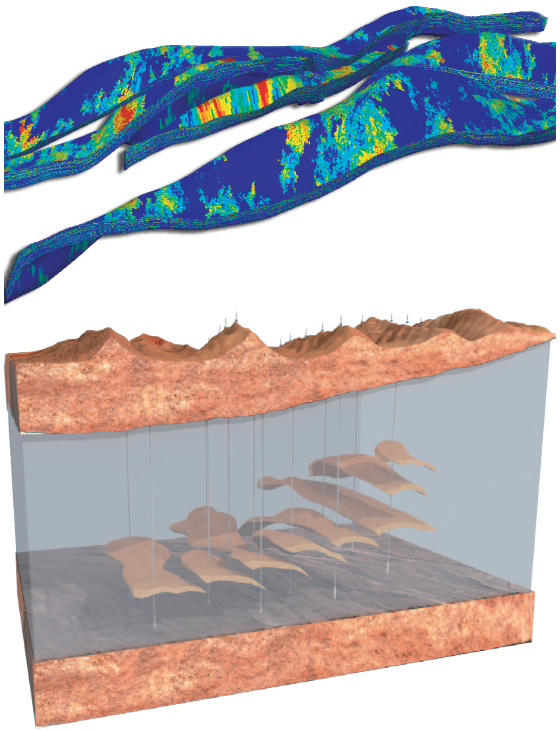
- Difficulties in seismic data acquisition, processing and interpretation caused by complex surface and severely superposed underground structure;
- Difficulties in drilling due to the existence of gravel layers and severely crept salt-gypsum formations;
- Difficulties in reservoir stimulation due to large burial depth and tight sandstone;
- High risks in downhole well testing due to high formation temperature and pressure;
- Difficulties in environmental protection due to the fragile ecological system of the mountainous Kuqa area.

With the joint efforts of our partners in the project, Schlumberger, Halliburton and Weatherford, we developed integrated solutions and innovative technologies to tackle the difficulties, and achieved the efficient development of the gas field. A total of 383bcm of gas in place were proven, the drilling period was reduced from 522 days to 290 days, single well productivity increased by more than 50%, and the success rate of downhole well testing reached 100%.

Innovative Technologies Applied

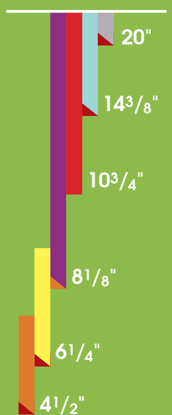
1. Seismic data acquisition and processing technology for complex subsalt structure in Kuqa piedmont

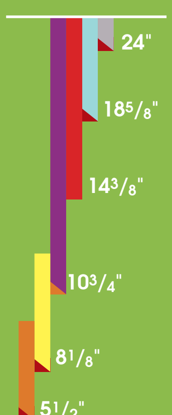
We renovated the high density wide azimuth seismic acquisition technology for mountainous land and TTI anisotropic pre-stack depth migration technology for irregular topography, and carried out 3,023km^2 3D seismic prospecting, covering the main zone of the Keshen structure. As a result, the quality of seismic data has been significantly improved, with the rate of class I-II data increasing from 40% to over 60%, and the error between drilling depth and predicted depth of subsalt targets decreasing from 4% to less than 2%.



2. Technologies for complex subsalt structure modeling and well-pattern optimization

On the basis of fault-related fold theory and salt-related tectonic theory, we established three kinds of structural models which have successfully guided seismic data interpretation, trap identification and well location optimization. Different structural models have different attributes in crustal stress, physical properties and fracture distribution, which control the productivity of gas wells. Thereby, a well deployment mode of "allocating wells along the higher part of the axis" was proposed, enhancing the drilling success rate from 72% to 92%, and the proportion of high-yield wells to 65%.





3. Technology for fast and safe drilling of ultra-deep complex wells

a. We independently designed two casing programs, TB II and TB II-B, and developed140ksi and 155ksi high strength, high anti-collapse casings, as well as gas sealing casings that are non API specified or even superior to API standards, eliminating the drilling troubles caused by multiple pressure systems which feature low pressure above salt, ultra-high pressure in compound salt-gypsum layer and relatively low pressure in reservoirs. Well completion with 5-1/2" or 7" casings is enabled, meeting the needs of gas production.

b. In cooperation with Schlumberger, the tailored PDC bits+vertical drilling system were applied on a large scale, resolving the contradiction between deviation control and increased bit weight. The rate of penetration was increased by 3-5 times, as compared to conventional drilling.

c. In cooperation with Halliburton, we adopted the high temperature high density oil-based drilling fluid to drill massive and deep salt layers, in order to avoid complicated accidents that used to occur frequently while using water-based drilling fluids. Consequently, the time ratio of complex accidents decreased from 29.69% to 6.38%, leading to obvious cost reductions. The killing fluids we prepared may have a density as high as 2.85g/cm^3, with the maximum applied depth of 8,038m at a maximum temperature of 180°C.

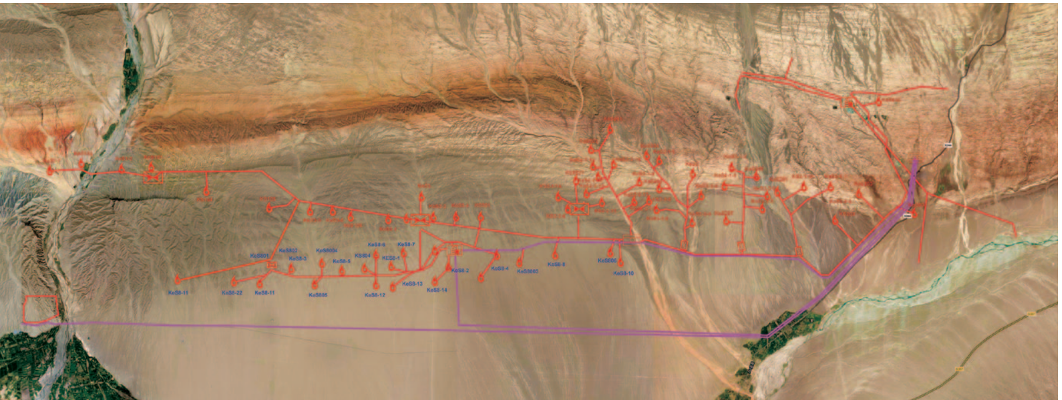
4. Technology for fracture network stimulation of fractured massive tight sandstone reservoirs

In order to increase the natural productivity of the fractured massive tight sandstone reservoirs, a R&D team named TASK was set up together with Schlumberger. Following a mode of geology-engineering integration, TASK conducted 3D geo-mechanical modeling and simulation of large rock sample fracturing, and revealed that the controlling factor of well productivity is the included angle between natural fracture trend and the direction of maximum principal horizontal stress in the reservoirs. To guarantee the implementation of fracture network stimulation, the team also developed a perforating gun with 210MPa pressure resistance and 200°C temperature resistance, a weighted fracturing fluid with temperature resistance of 180°C and specific gravity of 1.32, and a plugging/diverting agent that can be totally degraded under 160°C within 4 hours. Based on the above achievements, fracture network stimulation technology for fractured massive tight sandstone reservoirs was formed after repeated field trials. This technology has been used in more than 60% of the wells in Keshen gas field, enhancing the average daily output per single well from 140,000 cubic meters to 638,000 cubic meters.

Integration of Ground and Underground Engineering

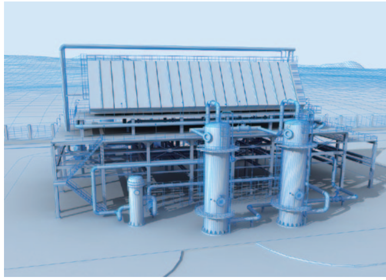
1. Selecting a place for the gas processing plant

Based on the well locations, capacity distribution and terrain condition of the 50km-long (WE) Keshen belt, and by using GIS, ground and underground integrated node analysis software and pipe network distribution simulation with multiple topologies, we selected a relatively flat and open place for the gas processing plant and the optimal distribution mode for the gathering and transportation pipe network. By doing so, the amount of earthwork was reduced and the engineering was more convenient with less costs. Meanwhile, there is reasonable room for new producing blocks in the surrounding area to be connected to the gathering and transportation radius to meet the overall development requirements in the future. The gathering and transportation pipeline is in a fishbone shape to minimize the mileage, shorten the construction period, and cut down overall investment in the project.



2. Introducing 3D modeling design and modular construction

Standardized design is adopted for ground works, facilitating the management of design, procurement and construction processes, and achieving unity in scale, speed, quality and efficiency. 3D modeling was introduced in designing the whole plant and the piping system, greatly improving the design schedule and quality. Factory prefabrication of process piping, pipe fittings and other facilities was adopted during the construction of the plant. The assembly-line modular method reduced the construction period to 10 months, whereas the planned period is 16 months. Additionally, 95 documents in terms of gas gathering and transportation standards have been formulated, focusing on wellsite and gathering station. Standardized design, modular prefabrication and skid-mounted construction of the well sites has enabled us to reduce the construction period of single well gathering and transportation work from 45 days to 20 days, meanwhile optimize station layout, and cut land use by 50%.



3.Improving energy efficiency

Sophisticated high-pressure throttling refrigeration technology is used in Keshen Natural Gas Processing Plant. By fully using the high-pressure energy of natural gas, there is no need to purchase any other high energy consumption devices such as compressors. Compared to traditional technology, it can cut energy consumption by 45%. Shell patented technology doubles the separation processing capacity of a single unit to 10 million cubic meters per day, reducing the difficulty in unit manufacturing, saving investment and improving reliability. On the other hand, simulation software is used to analyze the thermal exchange network and optimize the heat utilization system, in order to minimize energy consumption of heating medium furnace. The gas processing plant consumes only 70% of the energy that other similar-sized plants do.

Project Summary

Development of the field began in 2009, and the preliminary development program was worked out in July 2013. A total of 45 gas producers were completed and 140 km-long gas gathering pipelines were constructed. In July 2015, the Keshen Gas Processing Plant became operational, marking the official completion of the project on schedule, with an annual capacity of 5 billion cubic meters. By the end of 2015, Keshen had cumulatively produced more than 10 billion cubic meters of natural gas, serving as a stable supply source of the West-East Gas Pipelines.

The success of this integrated project offers an excellent example for the efficient development of gas fields of this kind, and it is of great significance to clean energy development and China's improved energy mix.