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SUPERENGINEERING

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Sulige Gas Field super project

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Sulige Gas Field, with an exploration area of 55,000 km^2, is located in the middle of the Inner Mongolia Autonomous Region and Northern Shanxi Province. Through 16 years of the continuous research, development and construction since its discovery in 2000, its proven geological reserves of natural gas reaches up to 1.64×10^{12} m^3 by the end of 2016. Sulige Gas Field is the only gas field with ultra-trillion cubic meters reserve in China, thus is the basis for establishing the "west-east natural gas transmission" and "Shanxi-east natural gas transmission" projects. Sulige Gas Field has the highest gas production in China, with an existing capacity of 2.3×10^{10} m^3 per year, comprising one-sixth of the natural gas production in China in 2016; 9632 natural gas wells have been put into production including 1220 horizontal well (Fig. 1), while six natural gas processing plants (Fig. 2), 135 gas gathering stations, 25 gas collecting main lines (1071 km), and 6 outputing external gas pipelines (484 km), have been put into production.

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The discovery, development and construction of Sulige Gas Field have received considerable attention from the society and won numerous awards. In May 2002, the Ministry of Science and Technology held a press conference to introduce major discoveries of Sulige Gas Field to the world (Fig. 3). The "Discovery and Comprehensive Exploration Technology of Sulige Gas Field" won the first prize in the 2002 National Science and Technology Progress Award. In 2003, the discovery of Sulige Gas Field was recognized by the academicians from Chinese Academy of Sciences and Chinese Academy of Engineering as one of China's Top Ten Scientific and Technological Progress (Fig. 4) and ranked third following the Rice Gene Map and the Shenzhou Spacecraft 3 and 4 launches. "The technology research on efficient economic development of Sulige Gas Field" was presented with the Special Prize of Scientific and Technological Progress Award at the provincial level in 2008. The construction of Sulige Gas Field was honored twice with the "Excellent Project of Productivity Construction" by China National Petroleum Corporation (CNPC) in 2009 and 2012. In 2013, the efficient development project of the Sulige large-scale dense sandstone gas field was selected as one of the world's three "Outstanding Achievement Award" projects in the 6th International Oil Technology Conference.

The main gas-producing sections of Sulige Gas Field are the sandstone in the 8th section of Shihezi Group and 1st section of Shanxi Group, both belonging to the sedimentary system of upper paleozoic braided rivers with a depth of 3200–3800 meters and the characteristic of the multi-layer gas compound. In 2000, the Su-6 well in the Shihezi group achieved the high-yielding industrial airflow of 1.2×10^{6} m^3 per day during the testing period (Fig. 5), which is marked as the discovery of Sulige Gas Field. A three-tier reserves of 7.327×10^{11} m^3 has been submitted in that year. Evaluation results in 2001–2004 showed that Sulige is a typical low-permeability, low-pressure, and low-abundance gas field, thereby indicating difficulty in developing effectively and resulting in a period of

Fig. 1 Seven cluster wells in Sulige Gas Field

Fig. 2 Natural gas processing plant in Sulige Gas Field

Fig. 3 Press conference of the Ministry of Science and Technology to introduce the discovery of Sulige Gas Field in 2002

Fig. 4 Press conference on Top Ten Scientific and Technological Progress of China and the World in 2002

construction stagnation. In 2003, the development ideas of "facing reality, relying on science and technology, innovating mechanism, simplifying mining, and lowing development cost" were introduced to encourage continuous technological breakthrough and management innovation. In 2006, a large-scale construction with the supporting capacity of 1.04×10^9 cubic meters was built and had achieved gas supply to Beijing in the same year, which indicated that Sulige Gas Field had basically achieved its cost-effective economic development. The 2007 special report of the Ministry of Land and Resources to the State Council indicated that "Sulige Gas Field has realized significant breakthrough in mining bottlenecks, and vitalized natural gas resources that is difficult to exploit". It also illustrates that China has a leading role in the world in development of large-scale non-conventional dense gas field. The natural gas production capacity of more than 2.3×10^{10} m^3 had been achieved by the end of 2013, thereby making Sulige Gas Field the largest gas field in China. The cumulated and basic proven reserves reach 1.64×10^{12} and 3.13×10^{12} m^3, respectively, by the end of 2016, thus making Sulige Gas Field a world-class super gas field.

The development evaluation after the discovery of

Fig. 5 Sulige Gas Field discovery wells — Su 6 well testing gas scene

Sulige Gas Field showed that the gas field has robust horizontal heterogeneity and vertical multi-stage overlap, and permeability less than 0.1 mD in the gas reservoir. Sulige Gas Field is a typical dense sandstone gas reservoir with no natural productivity. Through a long period of testing production on 28 wells for about 1 year, it was found that the average yield of a single well in the gas field was only 10,000 m^3/d, which could be produced stably only in three years with the extreme exploitation difficulty. The only way to effectively exploit the field is to increase the production of the single well and reduce the exploitation cost. A series of technological breakthroughs and field tests, including high-precision 2D earthquakes, drilling speed acceleration, downhole throttling (Fig. 6), trans-well connecting, mixed-phase metering, and oil tube domesticating, were conducted to improve the production of the single well and reduce the exploitation cost. The innovation works include 3 major professional series, 12 supporting technologies, and 5 key technologies, i.e., well location optimization, rapid drilling, partial pressure mining, underground throttling, and ground optimization. These innovations improved the production volume of the single well by 20%, reduced construction investment by 37%, which significantly reduced the exploitation costs, and tackled the technical bottleneck of the exploitation efficiency. The average comprehensive investment of the single well in the Sulige Gas Field was reduced from 1.3×10^7 CNY to less than 8×10^6 CNY. By the end of 2008, Sulige Gas Field already had achieved an annual production capacity of 7×10^9 m^3, and achieved the effective exploitation of gas field.

After the effective exploitation of gas field through the technical research, the period of nation's rapid demand growth in natural gas comes. Sulige Gas Field covers a large area, thereby indicating difficulties in achieving rapid exploitation by relying solely on the engineering and technical strength of Changqing Oilfield Branch. In August 2005, in order to accelerate the exploitation process of Sulige Fas Field, CNPC broke the restriction of internal operation system, innovated the exploitation mode, and proposed the "5 + 1" cooperative exploitation mode, which divided the Sulige Gas Field area of Changqing

Fig. 6 Images of the three kinds of actual underground throttles

Oilfield Branch into 7 risk operation blocks. By means of bidding, five unlisted enterprises including Changqing Exploration Bureau, Liaohe Exploration Bureau, Sichuan Administration, Dagang Group and North China Administration, were selected to participate in the exploration of Sulige Gas Field in form of risk operations. The five cooperators provided funds and confronted risks in the designated blocks, offering comprehensive operational services of the exploration and production operations for Changqing Oilfield Branch. Changqing Oilfield Branch was obliged to pay the service fee to cooperators according to the contract only when oil and gas were produced in the block. The "5 + 1" cooperative exploitation mode significantly motivated the enthusiasm of the unlisted enterprise, and broke the internal "transactions between related departments" system and geographical constraints. Because the cooperators' profits depended on the amount of gas production, a platform for the technical competition was built. This mode gave full play to the overall advantages of CNPC, and promoted the rapid progress of engineering technology, which are highlighted by the continuous progress of rapid drilling technology for straight wells, directional wells and horizontal wells in Sulige Gas Field, and the continuous refreshment of the fastest drilling records. This mode effectively promoted the reduction of development costs and accelerated the exploration process of Sulige Gas Field.

Sulige Gas Field covering a large area with large amount of production wells, large workload of ground construction, numerous construction units, therefore was facing the great difficulty in management coordination because the traditional management mode could not meet the needs of large-scale construction and operation of the Sulige Gas Field.

Changqing Oilfield Company actively practices in the construction of Sulige Gas Field, and fully implements a standardization design, modular construction, digitization management and marketization operation (Figs. 7–8). This construction mode has shorten the construction period, significantly reduced the daily workload of the patrol, improved work efficiency, reduced safety risks and integrated costs of exploitation. This mode can not only ensure the quality, safety and efficiency of exploitation, but also protect grassland environment, and construct a harmonious gas fields. The levels of design, construction, and management have been completely improved. The engineering management practices and achievements of Sulige Gas Field are known as the "Sulige Model" in the oil industry.

Sulige Gas Field went into full operation in 2006. At the end of 2007, the daily gas production reached 1.0×10^7 m^3. The daily gas production maintained an upwards trend for six successive years, with an annual increasing amount of approximately 1.0×10^7 m^3. In January 2014, the daily gas production reached 7.0×10^7 m^3. In 2016, the natural gas production reached 2.265×10^{10} m^3 and was ranked the biggest gas field in China, became the main supplier of gas for 8 big cities including Beijing, Shanghai, Tianjin, Xi'an etc. Its production volume could be sufficient to satisfy the requirements of citizens in Beijing for 12.6 years. Sulige Gas Field has operated safely and constantly since it was found, and the cumulative production of natural gas is

Fig. 7 Standard and digital wellsite of Sulige Gas Field

Fig. 8 Digital production management platform of Sulige Gas Field

1.48425×10^{11} m^3, which can meet the requirements of the entire country for over 8 years (assuming that 3×10^8 people use gas). It has effectively guaranteed the gas demand of the capital, the areas around Bohai Sea and the provinces around the gas fields, especially in winter, the requirement peak of gas. Its comprehensive benefits are remarkable, and it realized the technology, environmental, and harmonious developments.

The effective development of the large-scale Sulige Gas Field not only provides considerable clean energy for the Beijing-Tianjin-Hebei region and the five provinces surrounding the gas field but also exhibits an important guiding significance for the natural gas exploration and development of natural gas in the Erdos Basin. The development, construction and operation of Sulige Gas Field super engineering indicate that China has reached a global leading position in the large unconventional natural gas development area. “Sulige Model” can be an applicable reference model for the exploring and developing similar domestic and international gas fields.