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Research Article

Technical ideas of recovery enhancement in the Sulige Gasfield during the 13th Five-Year Plan☆

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Abstract

Based on the exploration and development achievements of the Sulige Gasfield in the Ordos Basin, tight sandstone gas yield has been increased essentially in China. Recovery enhancement is always the core subject in researches. In this paper, the development history of the Sulige Gasfield was reviewed focusing on the technological progress in single well production enhancement. Then, the technical ideas on and countermeasures for transforming the traditional development modes and increasing recovery factor were discussed. It is shown that the development technologies in the evaluation and the production enhancement and stabilization of giant tight sandstone gas reservoirs are changed progressively. The fast increase of gas production in this field is made possible by well location arrangement technology based on sweep spot screening, horizontal well development technology, well type and well pattern optimization technology, fast drilling technology, reservoir stimulation technology, drainage gas recovery technology and integrated construction mode. And finally, the technical ideas of recovery enhancement during the 13th Five-Year Plan were proposed in nine aspects, including gas field development, planning and evaluation technology based on single-well life cycle analysis; dynamic evaluation and infilling technology for mixed well patterns targeting recovery enhancement; one-shot recovery enhancement technology for a new areal pattern area with integrated multiple well patterns and multiple series of strata; reserve evaluation model based on risk and benefit evaluation; gas-well precise management technology with multi-dimensional matrix; potential tapping technology for low production and low efficiency wells; novel wellsite environmental protection technology; surface process based on integrated equipments; and C_3^+ mixed hydrocarbon recovery technology. It provides technically reliable support for the development of tight sandstone gas reservoirs in the Sulige Gasfield during the 13th Five-Year Plan.

Keywords: Ordos Basin; Sulige Gasfield; Tight sandstone gas reservoir; Heterogeneity; Development technologies; Recovery factor; Comprehensive research; Scheme

Tight sand gas is an unconventional gas developed on the largest scale in the world. It is characterized by widely contiguous distribution, absence of gas–water contact (GWC) and unapparent gas reservoir boundary [1–8]. Tight sand gas in China is characterized by thin gas layer, low gas saturation, low reserve abundance and large burial depth [9–16], making it more difficult to be economically developed than abroad. Now, China is entering a new period when equal attention is

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paid to conventional and unconventional gas development [17−23]. The innovation of development techniques [14−16,24−42], and especially the breakthrough in geologic theories [43−47], allows for the economical and effective development of some low-quality tight sandstone gas reservoirs that could be developed only with low or even no benefits [36,48,49]. Tight sand gas, with its proved reserves in place accounting for more than 40% of the total proved gas reserves in China, has become the main force for increasing gas reserves and output in China. The Sulige Gasfield in the Ordos Basin and the Upper Triassic Xujiahe gas reservoir in central Sichuan Basin are the typical representatives of tight sand gas [9−16,22−49]. It has become a consensus to preferentially develop tight sand gas among unconventional gases [8−22].

The Sulige Gasfield is an onshore tight sand gas field with the largest proved reserve in China. Its output reached 235.3×10^8 m^3 in 2014, accounting for more than 65% of the total tight sand gas output of China in that year [22,23]. Thereby, it has promoted the development of tight sand gas in China to achieve a qualitative leap, and has made a great contribution to the alleviation of tight gas supply and demand situation in China. By virtue of solid geoscience theory, scientific storage and production technology, advanced and applicable principles and rational resource allocations, the tight sand gas reservoir development project of the Sulige Gasfield was awarded one of the three excellently executed projects in the 6th International Petroleum Technology Conference and Exhibition (IPTC) held in 2013. It was the first international award and recognition obtained by China in the field of tight sand gas reservoir development. The gas field is characterized by low permeability, low pressure, low yield and strong heterogeneity [22−28,36,48]. The major geologic conditions for the formation of large tight sand gas reservoirs in the gas field include gentle structures, wide distribution of source rocks, stable sedimentation, wide distribution of reservoirs, constructive diagenesis, distribution of relatively high permeability reservoirs, and short range migration and efficient accumulation of gas, etc [15,36]. The reservoir is highly heterogenetic and its physical properties are poor, resulting in low single well controlled reserve. When a vertical well is used for development, the single-well output is low, the production decline is fast, the production plateau is short and the recovery percent of reserves is low [23−28]. Furthermore, the ecological environment of the work area is fragile. Therefore, it is faced with many technological challenges to achieve the targets of improving gas recovery, reducing development cost and building a green and harmonious gas field [22−25]. In view of this, by reviewing the development history of the Sulige Gasfield and systematically summing up the key technologies for scale and beneficial development, this paper analyzes the progress of technologies for enhancing single-well output and discusses the technical countermeasures for transforming the traditional development mode and improving gas recovery, in the hope of presenting valuable information and tamping technical base for a long-term stable production of the gas field and a smooth supply of gas in China.

1. Development history and main achievements

The Sulige Gasfield, located in the northwestern Yishan slope of the Ordos Basin, is a gentle west-dipping monocline. The main gas-bearing zones consist of fluvial sandstone reservoirs of the 8th member of Lower Shihezi Fm and the 1st member of Shanxi Fm of Permian, Palaeozoic, characterized by low permeability, low pressure, low yield and strong heterogeneity, with a burial depth of 3000−3600 m and a thickness of 140−170 m. The sedimentary environment is a terrestrial braided river sedimentary system on the whole, and can be divided into channel bar, channel fill and flood plain microfacies. Widespread lithological traps are developed, and the sedimentary environment can be divided into 4 zones (east, central, west and south) [23−25]. The exploration area is 5.5×10^4 km^2, with the total gas resources exceeding 5.0×10^{12} m^3, the submitted proved and basically proved gas in place being 4.0×10^{12} m^3, and the cumulative gas output being more than 1240×10^8 m^3. It is a gas field with the largest reserve scale and the highest annual and cumulative gas output in China up to now.

Large-scale natural gas exploration started in 2000 in the Sulige area, when 120×10^4 m^3/d high-yield absolute open industrial gas flow was obtained from the 8th member of Lower Shihezi Fm in Well Su 6, and 5336.52×10^8 m^3 uncompartmentalized proved gas in place (GIP) was submitted, marking the discovery of the Sulige Gasfield. Afterwards, in the light of the exploration concept on large lithologic gas reservoirs (namely, exploring facies belts in the whole area, anatomizing main sands on the whole, and evaluating high permeability areas intensively), a total of 40 exploration wells were deployed, but the test outputs were largely different. Therefore, as a new type of resources in China, tight sand gas reservoirs are face with challenges in terms of reservoir recognition and development strategies. By virtue of strengths throughout PetroChina, major technologies are formed for different development stages, contributing to the finalization of the largest gas field in China and a great-leap-forward development of similar gas reservoirs. The development history of the Sulige Gasfield can be divided into three stages, i.e. evaluation, production enhancement and production stabilization. Currently, the Sulige Gasfield is at the production stabilization stage. The main development technologies exhibit a “progressive change” − from qualitative to quantitative evaluation, from overall framework to classification evaluation, from single well to well cluster production, and from single well pattern to multi-well mixed areal well pattern production. Supporting technologies are changing from import techniques to independently-developed techniques, factory-like operation and volume fracturing. Surface technologies are developed towards skid-mounted modes and digital modes. With these changes, single-well output and recovery factor are expected

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