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Research article

Technologies and countermeasures for gas recovery enhancement

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Abstract

Since 2000, China has been ranked as one of the top countries in gas production. Nevertheless, the domestic gas production can hardly satisfy the need of national economic development. Besides, an increasing number of gas fields have come to the middle or late development stages, and most gas reservoirs have low recovery efficiency due to the low permeability and water drive nature. Therefore, gas recovery enhancement has become an urgent issue. At present, the oil recovery enhancement is well defined, and there are methods describing the remaining oil and a complete set of mature EOR (enhanced oil recovery) technologies. However, the definition and description of EGR (enhanced gas recovery) are still undermined, and the description method for the distribution of residual gas and EGR technologies are almost unavailable. In view of this, by reviewing a wealth of related literatures, we defined EGR and also described the remaining gas distribution based on the remaining gas abundance. In addition, collecting three typical types (low-permeability, condensate and edge/bottom water) of major gas reservoirs developed both at home and abroad, we summarized the geological and development characteristics, and found out the obstructions in the development. In response, we concluded and analyzed the relevant technologies and methods for enhancing the gas recovery of such reservoirs, and proposed the suggestions about EGR technology development, which provides a significant reference and popularization basis for EGR measures in fields.

Keywords: Natural gas; Reservoir; EGR (enhanced gas recovery); Low-permeability gas reservoir; Condensate reservoir; Edge/bottom water drive gas reservoir; Technology; Countermeasure

1. Introduction of EGR (enhanced gas recovery)

As a kind of cleaner, higher-quality, more economic energy and industrial chemical, natural gas plays a more and more important role in the national economy, and 21st century will be the one of natural gas [1,2]. A majority of gas reservoirs are featured by low-permeability, water-flooding and low gas recovery factor. In addition, natural gas consumption in China rapidly rises year by year. Therefore, EGR plays a vital role in national economy and society. EGR, i.e., enhanced gas recovery, refers to the technologies, approaches or processes applied to enhance gas recovery factor on the basis of current economic and technological conditions as well as gas recovery factors obtained from natural depletion like water drive and gas drive. In terms of an oil reservoir, primary oil recovery refers to natural depletion, secondary oil recovery refers to water injection for supplementing reservoir energy, and tertiary oil recovery or EOR refers to gas injection or chemical flooding. While as for gas reservoir development, primary gas recovery refers to natural depletion development and EGR refers to other technologies and approaches capable of enhancing recovery factor of remaining gas or reservoir producing level like putting back on the production of watered-out well, water-injection, gas-injection, chemical-injection and water-plugging oil reservoir recovery factor is the product of oil displacement efficiency and sweep efficiency. EOR is focusing on improving oil displacement efficiency (such as chemical flooding) and sweep efficiency (such as gas-drive). As for middle and high-permeability gas reservoirs, there will have pressure drop so long as any well is producing and the corresponding sweep efficiency can be regarded as 100%. Well in-filling for such kind of gas reservoir can only increase

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the gas recovery rate, rather than the gas recovery factor. As for low-permeability tight gas reservoirs, gas reservoir recovery factor can be enhanced through well in-filling or horizontal well drilling due to its small pressure sweep area. As for dry gas reservoirs, relatively higher gas reservoir recovery factor can be achieved and the gas displacement efficiency is uninvolved in case of no waterflooding or other injection treatments. The residual gas distribution correlates positively with reservoir pressure, which can be applied to describe residual gas distribution. As for water-flooding or gas injection reservoir, the residual gas abundance rather than pressure distribution is preferred to describe the residual gas distribution of it due to the existence of gas displacement efficiency. The gas recovery factor of such kind of gas reservoir is relatively low due to the low gas displacement efficiency of waterflooding and corresponding water-block effect.

In this paper, we systematically investigated the mainstream EGR technologies used in low-permeability gas reservoirs, condensate gas reservoirs and edge/bottom-water gas reservoirs that have been developed up to now. Based on case studies, the applicable EGR technologies of different kinds of gas reservoirs are summarized and the EGR development suggestions are proposed.

2. EGR technologies for low-permeability gas reservoirs

The gas production contribution of low-permeability gas reservoirs is rising year by year in China. Industry experts state that stable production and production increase of natural gas in China will depend more on the production of low-permeability gas reservoirs. Therefore, more and more attentions will be drawn to the exploration and development of low-permeability gas reservoirs in China. From a geologic perspective, low-permeability gas reservoirs are featured by strong heterogeneity, high shale content, low porosity and low permeability, high capillary pressure, high water saturation, complex gas-water distribution, etc. Gas reservoir development performances include low natural productivity, rapid pressure decrease, rapid production decline, and serious well-bore liquid loading in the middle/late development period. Unreasonable development modes will result in early large-scale water breakthrough, abnormally high reservoir abandonment pressure and low gas recovery factor. Commercial gas output can only be obtained by implementing some stimulations, and the common methods include drilling horizontal wells and fracturing vertical wells.

Stimulation in low-permeability gas reservoirs runs throughout the entire process from geology, well drilling, well completion, gas reservoir engineering to reservoir decommission. The primary goal of reservoir stimulation is to increase well productivity, ultimate recovery factor, and ultimately improve economic profits by increasing reservoir permeability. The EGR technologies for low-permeability gas reservoirs are summarized as in Table 1.

In view of the geology and development characteristics of low-permeability sandstone gas reservoirs in China and considering current tight gas reservoir development experiences, the following suggestions are proposed:

1) A breakthrough need to be made in the technologies in the enriched area optimization and reservoir prediction due to the low-abundance and strong-heterogeneity of low-permeability tight gas reservoirs, and the favorable area that are applicable to economic development should be developed preferentially.
2) Tight gas reservoirs are featured by high flow resistance, starting pressure, strong stress sensitivity etc., and the traditional continuum flow theory is no longer applicable. Therefore, it is necessary to develop flow theory in non-continuous porous media.
3) Domestic and overseas practices show that horizontal wells are an effective means of the development of low-permeability tight gas reservoirs. The multi-stage fracturing technology for horizontal wells and multi-layer fracturing technology for vertical wells should be developed with independent intellectual property.
4) Low-permeability tight gas reservoirs are developed by a large number of wells and the corresponding controlled areas are small. Well-infilling is an effective means to enhance gas recovery factor and it is of great necessity to identify the economic limit of well-infilling.
5) Down-hole throttling technology has been widely and successfully applied in Sulige gas field. This technology can save investment and simplify process and is worthy of further promotion.
6) Low-permeability gas reservoirs are usually featured by low productivity and poor profit, and many gas reservoirs have reached the margin of economic development. Therefore, cost-reduction development technologies must be promoted in the whole development process.
7) Shortage of water resources in China limits the application of large-scale hydraulic fracturing technology and exploding stimulation technology in reservoir should be promoted.

3. EGR technologies for condensate gas reservoirs

Condensate gas reservoirs are a kind of special and complex gas reservoir with very high economic benefit. Currently, most of the condensate gas resources that have been discovered in China are distributed in Xinjiang province and offshores. High-content and large reserves of condensate oil in the Tarim Basin are unparalleled in China. Most condensate gas reservoirs in China are middle-low condensate oil content saturated gas reservoirs. Natural depletion is mostly adopted, resulting in low recovery factor, and some reservoirs have entered middle/late development periods. Therefore, the key issue is how to improve the recovery factors of condensate gas and condensate oil in these condensate gas reservoirs [16,17].

There are complex physical and chemical phase transitions in the development of condensate gas reservoirs, which results in complex development mechanisms and great development difficulties. As a result, there will be a lot of inevitable issues influencing productivity and condensate oil recovery factor, such as liquid damage, hydrate blockage, wellbore liquid loading and gas breakthrough. For effectively developing condensate gas