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Characteristics and resource prospects of tight oil in Ordos Basin, China

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Abstract: Efficient large-scale development of ultra-low-permeability reservoirs (0.3–1 mD) has been achieved in the Changqing Oilfield, Ordos Basin of China. According to unique features of petroleum exploration and development in this basin, tight oil herein refers to petroleum that occurs in oil-bearing shales and interbedded tight sandstone reservoirs adjacent to source rocks with ambient air permeability <0.3 mD. Tight oil in tight sandstone and shale have generally not yet experienced large-scale long-distance migration. In the Yanchang Formation, tight oil has mainly accumulated in the semi-deep to deep lacustrine facies, typically in oil-bearing shales and tight sandstones of the 7th member oil-bearing formation and tight sandstones of the 6th member oil-bearing formation in the center of the basin. Tight oil resource in the Ordos Basin is characterized by wide spatial distribution, excellent source rocks, extremely tight sandstone reservoirs, complex pore throat structures, poor physical properties, high oil saturation, good crude-oil properties, and low reservoir pressure. A fundamental feature of the continuous oil and gas accumulation in tight oil reservoirs is the widespread development of nano-scale pore-throat systems. In the Yanchang Formation, most of connected pore throats in tight sandstone reservoirs have diameters greater than critical pore throat diameter, allowing oil and gas migration in the tight reservoirs. According to contact relationship between tight reservoirs and source rocks, three types of tight oil reservoirs are identified in the Yanchang Formation, i.e., tight massive sandstone reservoir, sand - shale interbed reservoir, and oil-bearing shale reservoir. In the Ordos Basin, tight oil is widely distributed in the 6th and 7th members of the Yanchang Formation, with total resources estimated to be 3×10^9 t. These include $>1\times10^9$ t of oil resources in shale in the 7th member of the Yanchang Formation and approximately 0.9×10^9 t and 1.1×10^9 t of tight sandstone oil resource in the 6th and 7th members of the Yanchang Formation, respectively. These tight oil resources are the realistic resources addition for the oilfield, which can ensure an annual production of 50×10^6 t of oil and gas equivalent and maintain long-term stable oil production in the Changqing Oilfield, Ordos Basin, China.

Key words: *tight oil; tight sandstone reservoir; shale reservoir; resource potential; Yanchang Formation; Ordos Basin*

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1 Introduction

Tight oil is a new hot spot of global exploration and development of unconventional oil and gas resources following shale gas (Liang et al., 2011; Sun et al., 2011; Zou et al., 2011a; Jia et al., 2012a). Tight oil plays a crucial role in the global energy structure, and commercial development of tight oil has been achieved in a number of countries such as the United States, Canada, and Australia (Zou et al., 2011a; Yan et al., Lin et al., 2011). Despite their abundance in China, exploration and development of unconventional oil and gas resources remain in an early stage in this country (Guan et al., 1995; Zou et al., 2010a).

Ordos Basin is rich in tight oil resources and has great potential for oil exploration and development. Over the past decade, PetroChina Changqing Oilfield Company has overcome difficulties related to low and ultra-low-permeability and achieved an annual increase of (1–3)×10^8 t in proved reserves for 10 consecutive years. By the end of 2015, the submitted proved reserves have accumulated to 4.154×10^9 t, including 2.156×10^9 t in low-permeability reservoirs (<1 mD). Changqing Oilfield Company has successfully achieved efficient large-scale development of tight oil reservoirs with ultra-low-permeability (0.3–1.0 mD) and innovated development technologies, typically in Huaqing Oilfield. In 2015, crude oil production in Changqing oilfield exceeded 25×10^6 t. Presently, field research of oil reservoirs with low permeability of 0.3–1.0 mD is ongoing in Changqing Oilfield. Laboratory researches and field experiments are conducted on shale oil in reservoirs of the 7th member of the Yanchang Formation with permeability <0.1 mD.

To date, there has been no consensus on the definition of tight oil. Zou et al consider that tight oil is the petroleum that co-exists in source rocks and accumulates in various types of tight reservoirs after short-distance migration, and tight oil reservoirs mainly consist of tight sandstone and tight limestone, with the in-situ matrix permeability less than or equal to 0.1 mD (reservoir surface-air permeability <1 mD) (Zou et al., 2012a,b). Jia et al consider that tight oil is the petroleum that occurs in a free or adsorbed state in source rocks or tight reservoir rocks (e.g., sandstone and carbonate rock) interbedded with or adjacent to source rocks, such oil accumulation has not experienced large-scale long-distance migration, and the in-situ matrix permeability of the reservoirs is less than or equal to 0.1 mD (reservoir surface-air permeability <1 mD) (Jia et al., 2012b). As for tight oil represented by Bakken Oilfield in the U.S. (Lin et al., 2011), the in-situ matrix permeability of the reservoirs is 0.01–0.1 mD. All the above definitions of tight oil take the surface-air permeability <1 mD as the boundary. According to actual situation of petroleum exploration and development in Ordos Basin, reservoirs with surface-air permeability (herein referred to the permeability in surface atmosphere unless otherwise specified) <1 mD (in-situ matrix permeability <0.1 mD) are referred to as unconventional oil and gas resources, and those with the permeability of 0.3–1 mD are regarded as ultra-low-permeability reservoir. As of date, efficient large-scale development has been achieved in the abovementioned low-permeability tight oil reservoirs. To focus on our research targets, tight oil in Ordos Basin is defined as the petroleum that occurs in oil-bearing shales and tight sandstone interbed reservoirs adjacent to source rocks and with surface-air permeability <0.3 mD. Such oil resources, including tight sandstone oil and shale oil, have not experienced large-scale long-distance migration. As compared to the explored low- and ultra-low-permeability reservoirs, tight oil reservoirs feature complex accumulation mechanisms, fine pore throats, poor physical properties, and high filling content; as compared to such resources overseas, tight oil in Ordos Basin shows substantial differences in pressure coefficient, oil potential, reservoir brittleness, and natural micro-fracture development. Consequently, well-developed technologies overseas are not fully applicable to the exploration and development of tight oil in Ordos Basin. Based on the latest advances of tight oil exploration in Ordos Basin, this study elaborates major geological characteristics of tight oil and preliminarily assesses and forecasts prospects of tight oil resources in Ordos Basin, in attempt to promote tight oil exploration and related geological research.

2 Characteristics of tight oil in Ordos Basin

In Ordos Basin, tight oil of the Yanchang Formation has mainly accumulated in the semi-deep to deep lacustrine facies, typically in oil-bearing shales and tight sandstones of the 7th member in the basin and tight sandstones of the 6th member in the center of the basin. Such tight oil is characterized by wide distribution, superior hydrocarbon source rocks, tight sandstone reservoir, complex pore throat structure, poor physical properties, high oil saturation, good oil quality, and low reservoir pressure coefficient. Typical oil in the shale is identified in the tight reservoirs of the 7th member,where oil-bearing shales are widely distributed with large thickness. Typical tight sandstone oil is identified in sandstone reservoirs of the 7th member and reservoirs of the 6th member in the center of the lacustrine basin. These oil-bearing formations are adjacent to high-quality source rocks and feature excellent source rock conditions, good source - reservoir configuration, and tight reservoirs.

2.1 Wide distribution of oil-bearing shales and high-quality source rocks

During deposition of the Late Triassic Yanchang Formation, the Indosinian movement led to the formation of a large-scale inland freshwater lacustrine. During deposition of the 7th member of Yanchang Formation, the basin reached maximum scale and developed major source rocks consisting of black shale, and dark mudstone (Yang and Zhang, 2005; Zhang et al., 20006).

In Ordos Basin, oil-bearing shales mainly are developed in the lower part of the 7th member. The oil-bearing shales are NW-