1 Introduction

The technology breakthrough in the exploration of shale gas and tight oil has greatly extended the global fossil fuel resources (Jia et al., 2012; Zou et al., 2012; Qiu et al., 2013). Although shale oil has been the global hot topic in the study of unconventional resources, there are varied definitions with respect to shale oil by different researchers. In this paper, as suggested by Zou et al. (2013), the term ‘shale oil’ refers to petroleum resources stored in organic-rich shale with abundant nano-scale pores. Our study mainly focuses on the shale oil distribution and corresponding reservoir characteristics in the Qijia-Gulong depression of Songliao Basin, and the purpose is to find favorable exploration targets in support of local exploration strategy theoretically.

2 Potential Shale Oil Occurrence

The Songliao Basin has two sets of excellent source rocks which were formed during transgression periods, of which the source rock of Qingshankou formation is in oil-window stage with great oil potential and is the main source rock for conventional oil and gas resources in the Songliao Basin. As shown in Fig. 1, intensive geochemical analyses of a series of key wells show that source rocks of the Qingshankou 1st member (K2qn1) are rich in organic content, especially in the central depression, and have high residual hydrocarbon content according to pyrolysis S1 value. Regionally, there are 2-3 interlayers of oil-shale at the lower part of the K2qn1 member and they have the highest organic content and S1 value. The overlying source rocks of Qingshankou 2nd-3rd members have less organic content with both organic content and S1 value decreasing upward. Thus, the K2qn1 member and K2qn2 member are the main target layers of shale oil exploration. In order to derive a regional map of residual hydrocarbon content and find favorable shale oil exploration targets, a technique using wireless logs to model pyrolysis S1 values was introduced and the practice shows that the model is precise enough to observe the variation of residual hydrocarbon content in source rocks. We have modeled 130 wells in the Qijia-Gulong depression and Longhupao depression, and pyrolysis S1 value at each layer was determined. The result shows that, in the K2qn1 member, pyrolysis S1 values are in the range of 1-2.5 mg/g, with the highest values located in the center and south of the Gulong depression and in the Longhupao depression, whereas in the Qijia depression mainly in the range of 1-2 mg/g. In the K2qn2 member, S1 values range 0.5-1.5 mg/g with the Gulong depression having higher S1 value (1-1.5 mg/g in general) than the Qijia depression (0.5-1 mg/g in general). Source rocks of K2qn3 member have much lower S1 value than previous two members, ranging 0-1 mg/g. Therefore, source rocks with the highest content of residual hydrocarbon are mainly located in the Qingshankou 1st-2nd members in the Gulong depression.

The thickness of dark mudstone of the K2qn1 member is in the range of 50-80 m in the Qijia-Gulong depression with the thickness decreasing in the north of the Qijia depression. The thickness of dark mudstone of the K2qn1 member is in the range of 30-100 m with the Gulong depression having thicker dark mudstone than the Qijia depression. In the K2qn3 member, the thickness of dark mudstone ranges 40-340 m with the thickness decreasing from the Gulong depression (160-340 m) to the Qijia depression (40-150 m). Given lower content of residual hydrocarbon, although the K2qn3 member has thicker source bed, we suggest that the K2qn1 member with relative uniform thickness is the most favorable layer for shale oil exploration.
3 GOR of Shale Oil

The gas oil ratio (GOR) of oil detained in source rock is one of key factors affecting effective exploration. Conventional gas adsorption models, either constant coefficient (e.g. \( g = 20 \) mg/g TOC) or P-T models, assume that gas adsorption is independent, i.e. it is not affected by coexistent oil content. The fact is that residual oil in source rock can decrease gas detained by dissolving, while the dissolved gas in oil can decrease the oil detained in source rock by decreasing oil viscosity. In other words, oil adsorption in source rock is interacted by gas adsorption. Thus, we introduced a new model to calculate GOR of residual oil in source rock, which, based on mass balance, combine interact adsorption model (Hantschel and Kauerauf, 2010), oil/gas generation and in-source oil cracking kinetics. The model was calibrated using natural data (oil density, GOR data, etc.) from known oil reservoirs. The result is shown in Fig. 2. As shown in Fig. 2, in the oil window (i.e. \( R_o = 0.9-1.2\% \)), the GOR of expelled oil is lower than accumulated residual oil. While \( R_o < 1.0\% \), the GOR of instantly expelled oil is close to that of accumulated residual oil, whereas when \( R_o > 1.0\% \), the GOR of instantly expelled oil increases dramatically and is much higher than that of accumulated expelled oil. A statistic of GOR data from main oil-producing reservoirs in the Songliao Basin shows that they are in the range of 10-130 (m³/m³), in accord with our calibrated model. Applying the model in the Qijia-Gulong depression shows that the GOR of residual oil in the center and north of the Qijia depression generally is lower than 120 (m³/m³), whereas in the south of the Qijia depression and in the Gulong depression, the GOR is generally in the range of 120-240 (m³/m³). Given the same conditions, previous practice suggests that oils with higher GOR value are more fluent and can be recovered more easily. Therefore, the Gulong depression is the best target for shale oil exploration in our case.

4 Shale Oil Reservoir Characteristics

As to shale oil, shale acts as both hydrocarbon source rock and reservoir. Observation of BSE images shows that there are various types of pores present in mudstones, including intercrystalline pores, intergranular pores, organic pores, micro-fractures and etc. As shown in Fig. 3, the porosity distribution analysis shows that pores developed in mudstones are most in nano-scale with less micro-scale pores and diameters of most pores are less than 400 nm. In contrast, organic pores generally have diameters less than 50 nm. Mercury injection analysis shows that pore diameters in shale are in the range of 20-200 nm and the displacement pressure (\( P_d \)) is generally over 20 MPa, whereas the \( P_d \) of associated tight sandstone is less than 10 MPa. As reported by Huo et al. (2011), hydropyrolysis experiment result shows that the total organic carbon content (TOC) of excellent source rocks in the Songliao Basin is decreased by 50-60% when the maturity is over 1.1% \( R_o \), producing abundant organic pores. It seems that higher organic content will produce more organic pores after oil generation. Therefore, there are at least two advantages with respect to shale oil exploration in the
Gulong depression with higher thermal maturity: (1) more abundant organic pores; (2) as discussed above, residual oil has higher GOR value. Besides, another important hydrocarbon storage capacity of shale in the Songliao Basin can be expected from core observation, which shows that oils present in many shale breakages and micro-fractures.

References