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Preliminary evaluation of gas content of the No. 2 coal seam in the Yanchuannan area, southeast Ordos basin, China

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ABSTRACT

Gas contents are highly variable in coalbed methane (CBM) reservoirs of the Yanchuannan (YCN) area of the southeast (SE) Ordos Basin, China. We used diverse geologic data derived from more than five years of exploration to provide insight into the origin of this variability and the consequences of gas content on reservoir performance. Major factors affecting gas content variability include gas generation, migration, trapping and preservation. Gas generation affects gas content variability on the scale of the total resource, whereas gas migration influences the inhomogeneous redistribution of gas content on a regional or local scale. Gas trapping and preservation affect the "as-observed" content. The potential for high gas content is controlled directly by the composite result of gas generation, migration, trapping and preservation. CBM in the YCN area is produced from the relatively thick seam (~2.09 m and 8.05 m, with an average of 5.97 m) that is distributed through 450–1200 m of the stratigraphic section. Gas content tends to be structurally and hydrodynamically controlled in the order of simple structure (folds and small faults) > complex structure (large regional faults) and groundwater stagnant zones > runoff zones. Coal samples in the YCN area typically have Langmuir volumes between 31.86 and 46.51 cm^3/g, which correlates with coal rank. Reservoir heterogeneity including coal composition, pore structure and matrix moisture content may contribute to the heterogeneous gas content. Gas content is generally high where hydrodynamic trapping of gases occurs and may be anomalously low in areas of active recharge with downward flow potential and/or convergent flow where there is no mechanism for entrapment. In the YCN area, the most favorable area for CBM exploration and development is in the center block (block B), where great coal thickness, moderate burial depth, favorable hydrodynamics and an anticlinal trap coincide to yield high gas contents.

1. Introduction

CBM recovery from coal seams will both benefit mining safety and reduce greenhouse gas emission (Karacan et al., 2011). In addition, with the decline in conventional natural gas reserves and increased demand and price of gas, industry shows great interest in unconventional gas (CBM, shale gas) resources, which requires accurate estimation of CBM/shale gas potential and recoverable reserves to assist in its development. CBM resources are abundant in the middle-high rank coals distributed throughout the targeted southern Qinshui Basin (Su et al., 2005; Cai et al., 2011; Song et al., 2012; Liu et al., 2014) and the eastern Ordos Basin (Xu et al., 2012), China. Although many CBM exploration and basic research projects have been initiated, only a few studies on the preliminary regional CBM reservoir and resources have been conducted in the eastern Ordos Basin. This area has become a focus of much research and offers a new field of CBM exploration and development (Zhang et al., 2010; Tao et al., 2012; Xu et al., 2012).

The Ordos Basin is the second fastest developing district of the CBM industry in China. Large and diverse databases have been assembled on the geology and performance of CBM reservoirs in the Ordos Basin (Yao et al., 2009; Wei et al., 2010; Zhang et al., 2010; Tang et al., 2012; Yao et al., 2013) and on the assessment of CBM potential (Feng et al., 2002; Jie, 2010; Lu et al., 2011). The SE Ordos Basin has medium to high rank coals that have the great potential for CBM development. Previous studies estimated that the gas in place (GIP) for CBM in place in the eastern Ordos Basin and the entire Ordos Basin are about 9×10^{12} m^3 (Jie, 2010) and 10.72×10^{12} m^3 (Feng et al., 2002), respectively.

The YCN area covers an area of 679.6 km^2, which is considered to be the second CBM commercial pilot after the Southern Qinshui

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basin. Until March of 2012, 45 test and production wells were drilled in the YCN area, which has become the first CBM pilot-production field of Sinopec. Thirty-three wells have each produced about 16,000 m^3 of gas per day, accounting for a cumulative gas production of 284.6×10^4 m^3. In addition, 10 of these wells have gas production over 1000 m^3/d. Based on well testing results, the initial reservoir pressure ranges from 3.6 MPa to 10 MPa. Desorption pressure ranges from 2.19 MPa to 9.88 MPa, with an average of 3.58 MPa, which is favorable for gas desorption. The highest CBM production is $\sim$2632 m^3 per day. CBM proved reserves of the YCN area have remained relatively constant but have increased slightly over the past four years with increased CBM exploration and development for more deeply buried deposits. Because of this significant gas potential, the YCN area is considered favorable for CBM exploration and development. The increase in proved CBM reserves, despite the significant increase in production, is attributed to the efforts of smaller operators and independents in finding new reserves. CBM production and reserves are expected to increase as exploration continues in unexplored areas and as secondary recovery techniques using N_2, CO_2, or biotechnologies are employed (Busch and Gensterblum, 2011; Connell et al., 2011; Fallgren et al., 2013).

Understanding the factors that controlled gas content in coals is critical to developing an effective and successful exploration program. Therefore, we review the key geologic factors that affect gas content and discuss how these factors ultimately determine the gas content in coals. An evolution model of gas content based on a decade of CBM research in China is proposed (Fig. 1), which can be used to predict areas of unusually high gas content and, of equal importance areas of unusually low gas content values.

Large and diverse databases have been assembled on the geology and reservoir performance of the No. 2 coal seam in the SE Ordos Basin (Feng et al., 2002; Yao et al., 2009; Wei et al., 2010; Zhang et al., 2010; Jie, 2010; Lu et al., 2011; Tang et al., 2012). This paper synthesizes the available geologic, hydrologic, petrologic, and reservoir information to provide perspective on the ways that variable factors influence the gas content and therefore the viability of the CBM field for production. We begin with a review of the geologic framework of the SE Ordos CBM fields and continue

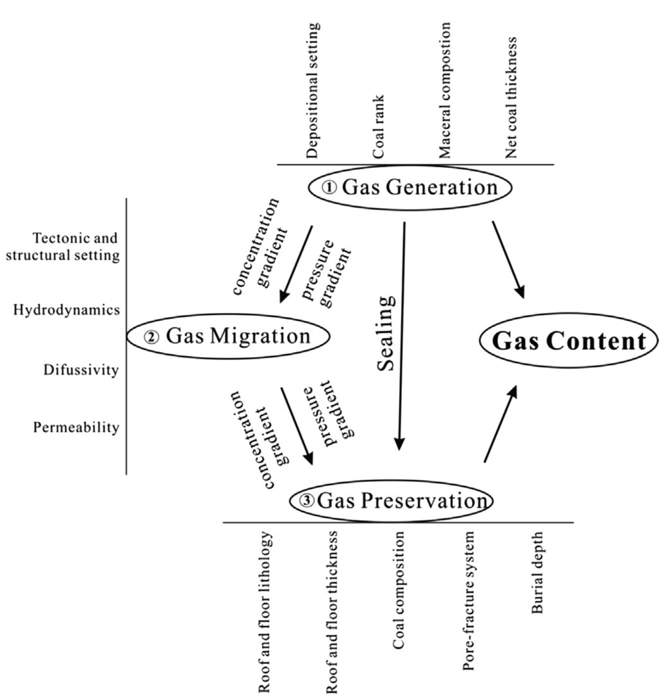

Fig. 1. An evaluation model of gas content.

with an evolution model of gas content. We, then follow with a discussion of factors controlling gas content. Finally, the paper concludes with a discussion of the relationship of gas content with related geologic variables.

2. Geologic framework

During the Cambrian to Ordovician periods, shallow marine carbonate was deposited on the ancient crystalline basement in the Ordos Basin following stable crustal subsidence (Stauffer et al., 2009). The Ordos Basin is located in northern China, which covers about 320,000 km^2. Thickness of sedimentary fill of the basin approach 5000 m. The Ordos Basin has been through three orogenies; the Indosinian, Yanshanian and Himalayanian orogenies. The deposited coal-bearing strata of the Carboniferous and Permian were altered by these three orogenies (Fig. 2).

The Ordos Basin can be subdivided into six structural units, including the Yimeng Uplift, the Weibei Uplift, the Jinxi Fault-fold Belt, the Yishan Slope, the Tianhuan Depression, and the Western Edge Fault Belt (Liao et al., 2007). The YCN area is located in the Hedong fault-fold belt (Zhang et al., 2011; Lu et al., 2011), which is within the Jinxi fault-fold belt (Lu et al., 2011), and near the SE edge of the Ordos Basin. Folds within the YCN area are not well developed. Only two folds exist in the northeast YCN area with 10–17 km NE axial strike. Strata of these two anticlinal wings are normally flat with a dip angle of $\sim 8^{\circ}$. The axial strike of most of the faults in the YCN area is NNE, NE and near S–N, partially E–W, which is consistent with the regional tectonics. The central YCN area is developed in two large NE-trending thrust faults (Fig. 3). In the southeastern edge of the YCN area, there is a normal fault.

3. Evolution model of gas content

Gas content, one of the most important controls on CBM producibility, is one of the most difficult parameters to accurately assess. Gas content is not fixed, but changes when equilibrium conditions within the reservoir are disrupted and is strongly dependent upon multiple geologic factors and reservoir conditions (Scott et al., 1994; Scott and Kaiser, 1996). The distribution of gas content varies laterally within individual thin coal seams, vertically among coals within a single well, and laterally and vertically within thick coal seams.

In general, gas content increases with depth and coal rank, but is often highly variable due to geological heterogeneities, coal composition and/or vagaries related to the analytical laboratory. Previous research has indicated that initial pressure increases gas content but that this effect diminishes $\sim$1000 m (Gensterblum et al., 2014). Although determination of migration direction for gas generally implies conventional gas, gas content in coals can be rebalanced, either locally, regionally or vertically, by generation of secondary biogenic gases or by diffusion and long-distance migration of thermogenic and secondary biogenic gases to no-flow structural boundaries such as hingelines or faults for eventual resorption and conventional trapping (Scott, 2002). Therefore, migration direction through isotopic and hydrodynamic studies is critical for determining the areas of higher gas content. Finally, good preservation conditions of CBM reservoirs are the last step for high CBM producibility. Therefore, gas content is a composite result of multiple factors including geologic, hydrodynamic, and petrophysical conditions and reservoir characteristics.

Exceptionally high gas contents do not necessarily guarantee high production rates if permeability is too low (Scott and Kaiser, 1996). And low sealing capability of roof lithology and thickness may also cause low gas content. Assuming that gas content reported from field test are reasonably accurate, there are many