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Original research paper

Geochemical characteristics of terrestrial shale gas and its production prediction significance in the Ordos Basin, China☆

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Abstract

In order to study the variation of shale gas composition as well as the carbon isotopic fractionation characteristics of terrestrial shale in the Ordos Basin, and ultimately establish a prediction model for shale gas production in order to monitor production capacity and effectively manage the development of shale gas, selected core samples from production wells were obtained for desorption analyses of their corresponding gas composition and carbon isotope. The desorption results showed that the methane content of the desorption gas is relatively low, the drying coefficient (C_1/C_{1-5}) ranges from 0.6 to 0.8, and the carbon isotope is relatively negative compared to other places. By means of the increasing desorption and production time, the drying coefficient and carbon isotope values of such samples show obvious carbon fractionation during gas adsorption/diffusion processes. The changes are more evident with increasing heavy hydrocarbons (C_{2+}) and heavier carbon isotope values. The drying coefficient shows good correlation ($R^2 > 0.8$) with the content of shale gas desorption per unit mass. A gas production prediction model was proposed to predict gas production throughout the life of the production well based on the relationship between the drying coefficients and gas production volume in the Ordos Basin.

Keywords: Terrestrial shale; Gas component; Carbon isotope; Gas production prediction model

1. Introduction

Gas component and stable carbon isotope value serve as key geochemical parameters to the research generation. The elimination and migration of hydrocarbon are of extensive significance in identifying the types of natural gas genesis, defining maturity of organic matters, and contrasting oil-gas sources [1−6]. Substantive simulation experiment results and onsite observed data by predecessors show that: in the course of migration of conventional gas in the formation pore system, understandable fractionation effect that occurs in carbon isotope, which, to be specific, is shown in preferential migration of methane relative to heavy hydrocarbon, isomerical butane relative to normal butane, and light carbon isotope relative to heavy carbon isotope [7−10]. The reasons behind this are differences in the chemical reaction activate energy, mass number, molecular structure or adsorbability of different components or different isotopic molecules in a generation, migration, and lastly, the preservation or dissipation course of natural gas [10,11]. As a non-conventional hydrocarbon

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resource, shale gas is characterized by self-generation and self-storage relative to the conventional gas reservoir. Generally, it does not migrate nor does it diffuse over a long distance, its component and carbon isotopic fractionation characteristics are more likely to be greatly different from those of conventional gas.

Research performed by predecessors believe that gas diffusion and adsorption are the major factors which influence migration of gas in shale or other tight stratum origins, making the gas generate components and stable carbon isotopic fractionation [6,9−11]. The main cause for gas diffusion to result in component and carbon isotopic fractionation is that methane is relative to heavy hydrocarbon, and light carbon isotope component is relative to heavy carbon isotope component, it has higher diffusibility that eventually causes gas components to be dampened and carbon isotope value to be on the negative side. The predecessors performed diffusion and analysis experiment on dry shale to find whether the gas diffusion front obviously abounded in the ^{12}C-methane and whether the migrated methane carbon isotope value could reduce by 30‰ [12,13]. Meanwhile, water-saturated shale can also cause large carbon isotopic fractionation generated in diffusion process of methane [6]. Some scholars have explored carbon isotopic fractionation model caused by gas diffusion migration [14−16].

The adsorption of clay minerals and organic matters for gasses will also lead to fractionation of stable carbon isotope. However, this has been barely delved into comparatively [17,18]. Fuex [17] conducted a methane adsorption experiment using a high polarity chromatography column. He found out that this chromatography column had lower affinity to non-polarity methane and that the carbon isotopic fractionation was smaller than 1‰. Gunter [18] conducted the same experiment using a 13 Å molecular sieve whose methane adsorptivity was stronger in finding our whether the methane carbon isotopic fractionation caused by adsorption could exceed 10‰. As the chromatography column was applied in the experiment it's characterized by dryness and high specific surface area compared to formation shale sample. It is hard to contrast the influence of adsorption displayed by the experimental result on methane isotope with a practical situation. However, at least the experimental result can validate possible influence of adsorption on carbon isotopic fractionation.

Lu [19] collected fresh shale core on top of the gas reservoir, measured the components of residue gas and carbon isotope value. Lu found out that the methane carbon isotope value at this position (from −36.6‰ to −25.5‰) was far larger than the counterpart in the reservoir (−41.9‰). It also increased as the depth became more sizeable; it was unrelated to physical properties of rocks and minerals characteristics. The research believed that the change of methane carbon isotope was primarily influenced by gas diffusion and clay mineral adsorption. Xia [16] considered gas adsorption and diffusion process and raised a gas continuous flow model to simulate isotopic fractionation phenomenon caused by migration of natural gas in coal and shale. This author believed that the early migration after gas generation would turn the carbon isotope to the negative side due to the strong adsorptive capacity of hydrocarbon source rock.

Han et al. [20] analyzed gas components and characteristics of carbon isotope as well as desorbed shale gas on site to discover that the ethane content increased regularly with the increase of desorption time in the desorption process of shale gas; the $\delta^{13}C_1$ value increased to a certain extent. Meanwhile, a handful simulation experiments on coal-seam gas also saw that the methane carbon isotope value increases with the surge of desorption time [21−23]. Gao et al. [24] analyzed basic geochemical characteristics of desorbed gas from the Upper Triassic shale in the Junggar Basin, it is generally thought that the shale gas in this region was dry gas with low carbon isotope value, exhibiting characteristics of the conventional low maturity situ sapropel type natural gas. Du et al. [25] analyzed components and carbon isotope and formulated that shale gas in the Yanchang Formation in the southeast of the Ordos Basin was dominated by pyrolyzed moisture. Additionally, the carbon isotope series was basically positive basically indicating that there's idiogenous gas was mixed in this segment.

To sum things up, current research on the components of natural gas and characteristics of carbon isotope in a non-conventional compact reservoir is mainly focused on describing basic geochemical characteristics, fractionation mechanism, and gas genesis, etc. There's deficient research on the correlation between the desorbed gas amount of shale or per well rate and geochemical change characteristics of. Thus, the paper collected onsite desorbed gas and gas sample from trial-producing well and analyzed components and carbon isotope, subsequently combining field data of production well to establish an effective single well shale gas yield prediction model to provide a useful reference for shale gas reserve estimate and dynamic monitoring of productive capacity.

2. Sample and experiment

2.1. Geologic background and sample

Mainly located in the southeast of the Yishan slope in the Ordos Basin, the researched area has a gentle structure with a strata dip of <1°. The main body is located in the Yan'an city within Shaanxi Province (Fig. 1a). The Mesozoic Ordos Basin experienced multistage sedimentation, polycyclic uplifting and reconstruction, and several other sedimentary cycles [26−28]. Thereunto, the Upper Triassic series in the Yanchang Formation is just a limnetic facies which the clastic successions series developed in the stable sedimentation period. The section Chang 7 has lithologic characters of mainly dark-colored shale, carbargilite, oil shale with the thickness being 70−150 m. Section Chang 7 is the main exploration target formation layer of hydrocarbon source rock and shale gas (Fig. 1b).

2.2. Experimental method

The research samples were mainly onsite shale desorbed gas sample. The onsite desorption of shale gas requires the