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A logging calculation method for shale adsorbed gas content and its application

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ABSTRACT

A large part of shale gas occurs in organic matter and clay mineral surfaces in an adsorption state (20–85%). In a shale reservoir, the pore surfaces of organic matter and clay minerals are the main locations for shale gas adsorption. However, calculating the adsorption gas content is a difficult problem in logging. In order to build a calculation model for adsorption gas, a series of experiments was conducted to understand the relationship between adsorption gas content, mineral type, and content in the Zhaotong Longmaxi formation. These experiments show that organic matter has the most specific surface area and is the most important adsorption matter in the reservoir, especially under low pressure. Clay minerals become more important as the pressure increases. The KIM formula, which is widely used in coalbed methane, was introduced in this work. At a certain temperature and pressure in a reservoir, the gas adsorption specific surface can be simplified as a function of total organic carbon and clay mineral content. The calculated results from the Zhaotong A well are in good agreement with the experiments. The well logging information is used to further calculate the clay minerals of the Zhaotong A well profile, the total organic carbon profile, and the adsorption volume profile. The adsorption gas and total gas of the Zhaotong A well Longmaxi group in a lower place had similar reductions, which is consistent with the field desorption experiment.

1. Introduction

The total gas in place (GIP) includes both adsorbed gas and free gas. Only a small fraction of shale gas occurs in kerogen, bitumen, and structural water in a dissolved state. The vast majority of natural gas occurs in organic matter and in clay mineral surfaces in an adsorption state (20–85%), or it occurs in pores and fractures as a free gas (Zou et al., 2010). Log interpretation models of the shale reservoir adsorption gas content can be built using logging data combined with core experiments in order to predict the effective adsorption of shale gas content and reduce the experimental cost. Decker et al. (1993) found that, in shale, the measured gas content and organic carbon content had a good positive correlation, but the organic carbon content and volume density had a very good negative correlation. In this way, a calculation model of bulk density and gas content was established to predict Antrim shale gas content, based on an isothermal adsorption and volume model. However, in some continental reservoirs, pores from inorganic matter dominate and organic pores do not develop, so it is not sufficient to only consider organic matter in the adsorption capacity. Cluff (2006) calculated the in situ resource of Delaware Basin Barnett shale and Woodford shale using the log interpretation parameters, based on the isothermal adsorption and volume model, but the parameters in the model were not easily determined. Utley (2014) calculated Fayetteville shale gas content using neural network key parameters; however, the results did not have a clear physical significance. Lewis et al. (2004) proposed a well logging calibration model based on an isothermal adsorption experiment and used the model in logging interpretation software by the Schlumberger Company. This method also did not consider the influence of inorganic matter in adsorption.

Methane gas is mainly adsorbed in clay minerals and organic carbon. Factors such as kerogens, the maturity of organic matter, the hydrocarbon expulsion intensity, the degree of pore development, and the amount water saturation all affect methane gas adsorption in shale (Jarvie, 2005). In this paper, based on experimental results using samples from the Zhaotong A well, the influence of organic pores and clay mineral pores on gas absorption is discussed and a new calculation model for adsorption gas content is proposed.

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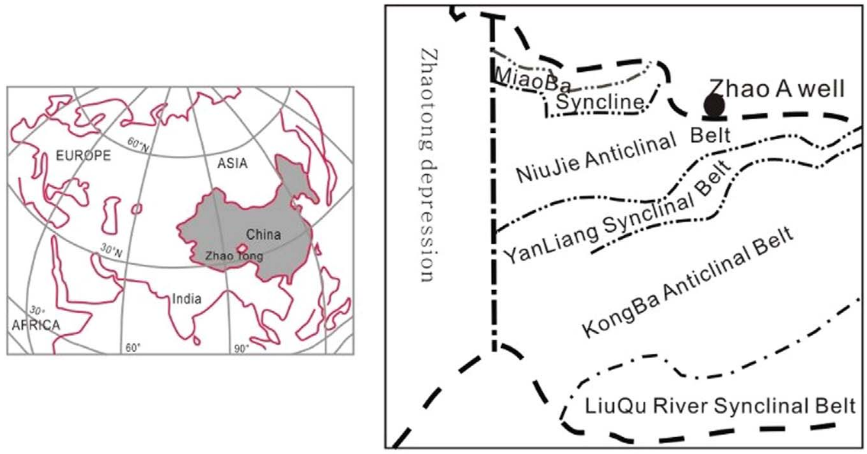

Fig. 1. The geographic location of the Zhaotong A well.

2. Block and experimental research work

The Zhaotong A well is located in the Zhaotong sag. It belongs to the Yunnan suck depression at the southwest edge of the Yangtze massif tectonic domain, and the subject is located in midwest region of the Weixin sag (Fig. 1), with the Sichuan basin to the north.

The research data were obtained mainly from 15 samples taken from the Zhaotong A well Longmaxi formation. We collected data on the isothermal adsorption, porosity, mineral type and content, total organic carbon, vitrinite reflectance, desorbed gas content, and specific surface area of the well. We also collected ECS logging data and conventional well logging data from well A. The type 300 isothermal adsorption instrument was used in the isothermal adsorption experiment, and the sample isothermal adsorption temperature was 30 °C. The isothermal adsorption method used the GB/T19560-2004 standards. The isothermal adsorption results are shown in Fig. 2, and the samples are described in Table 1.

3. The influence of adsorption matter content on adsorption capacity of shale

In actual shale reservoirs, the space for methane adsorption exists not only on the surface of organic pores, but also on the surface of inorganic pores. Shale reservoirs have strong heterogeneity. The adsorption ability is different and depends on the formation and structural evolution of the pores. Organic and inorganic pores differ from shale to shale.

3.1. Organic adsorption space

Organic pores are well developed in shale. In shales rich in organic matter, organic pores can even account for 90% of the total porosity. Radii of the organic matter pores can vary widely from 10 nm to 300 nm (Loucks, 2012). Organic matter pores can provide a favorable space for the adsorbed gas (Ross and Bustin, 2009). The development of organic pores is influenced by the comprehensive effects of organic matter abundance, organic matter type, maturity, and compaction. In general, the percentage of organic matter pores and total pores increases with increasing organic matter abundance and maturity.

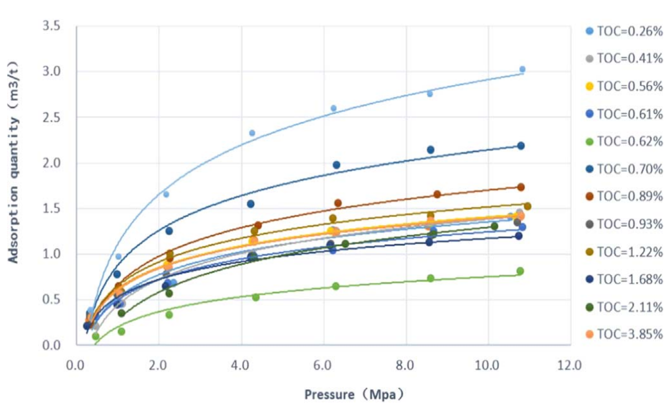

Fig. 2. Isothermal adsorption experiments in the Zhaotong A well (15 samples).

The Langmuir constant for organic matter varies for different kerogens, with a minimum value for I kerogen and a maximum for III kerogen. This is due to the generally low aromatization degree of I kerogen (Larsen and Aida, 2004).

The geochemical experimental results show that the shale vitrinite reflectance of the Zhaotong Longmaxi formation ranges from 2.7 to 3.8. We extracted kerogen from the shale, and Fig. 3 shows a type II adsorption curve of shale and kerogen. When the relative pressure equals 0.5, there is a bulge in the curve of shale and kerogen. Both curve shapes are similar and both have an obvious hysteresis loop. The specific surface of the shale ranges from 6.9 to 23.22 m^2/g with an average value of 15.10 m^2/g. The specific surface of the kerogen for this reservoir ranges from 38.63 to 193.10 m^2/g with an average value of 93.21 m^2/g. Thus, the kerogen's specific surface is much higher than that of the reservoir. Kerogen provides the main specific surface for the shale reservoir because its nanometer pores are well developed. In contrast, non-clay minerals such as quartz and feldspar have much lower specific surfaces and can be ignored. As seen in Fig. 4, the adsorbed gas content (V) has a positive correlation with total organic carbon. However, as the pressure rises from 1 MPa to 10 MPa, the covariance of total organic carbon and V reduces slightly.

3.2. Inorganic matter adsorption space

Clay minerals are the main diagenetic minerals in shale, accounting for about 60% of the rock (Zhai et al., 2014). Clay mineral pores are well developed and they also provide a lot of space for the adsorption of methane in the Longmaxi formation. The methane adsorption capacity of different clay minerals varies widely. From Table 2, we can see that montmorillonite has the largest specific surface area, but it is much less than that of kerogen. Thus, for the dry sample, the clay mineral adsorption capacity is in accordance with the size of the specific surface area: montmorillonite > kaolinite > illite. When the sample is in moisture balance, the adsorption capacity of the components changes: illite > montmorillonite > kaolinite (Passey et al., 2010).

In the Zhaotong Longmaxi formation, Fig. 5 shows that the clay mineral is mainly composed of illite, chlorite, and an illite smectite mixed layer. The illite smectite mixed layer has the largest adsorption capacity among the components of the formation's clay minerals. The