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Influence of stress and formation water properties on velocity sensitivity of lignite reservoir using simulation experiment

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ABSTRACT

To study the velocity sensitivity of a lignite reservoir under different stresses and formation water conditions, orthogonal experiments are performed with pH, salinity, and effective stress as the main factors, and evaluation indexes are extracted at different stages. The effects of the main factors on each index are analyzed by means of range analysis, variance analysis, and effect diagram to study the mechanism of velocity sensitivity in a lignite reservoir. Under a given effective stress condition, the change in lignite permeability with the variation of fluid pressure undergoes three evolutionary stages (stable-rise, decline, and fluctuation) and two effects (sensitization and velocity sensitivity effects) exist. On the basis of the seven evaluation indexes, an evaluation index (D_m) suitable for describing velocity sensitivity damage in the presence of sensitization stage is proposed. Extreme and variance analyses show that salinity is the main factor that controls the lignite sensitization (rise) stage. In the velocity sensitivity (decline) stage, the permeability attenuation rate is controlled by pH and salinity, and the sustained range of velocity sensitivity is affected by pH and effective stress. The fluctuation stage is mainly affected by effective stress. It is analyzed that pH mainly controls the migration and agglomeration of pulverized coal particles through hydrophilicity, and salinity controls the dispersion and agglomeration of pulverized coal particles through the zeta potential generated by an electric double layer. Effective stress influences the sensitivity of lignite reservoir by effecting pore structure.

1. Introduction

In recent years, lignite coal bed methane (CBM) has been extensively commercialized in the Powder River Basin and eastern Uinta Basin of the USA, the Alberta Basin of Canada, and the Surat Basin of Australia, thereby attracting the attention of many countries, including China [1]. China has abundant lignite methane resources ($3.88 \times 10^{12}\,m^3$), accounting for approximately 10.53% of the total CBM resources in the country, and it has great potential for exploration and development [2]. The exploration and exploitation of lignite CBM in China has made a breakthrough in recent years, but the blocks (major CBM exploration and development provinces) and basins involved are limited and have not yet developed in scale. The basic geological conditions for CBM accumulation in lignite seams have been studied for many years. The results obtained in these studies have led to the conclusion that methane adsorption of lignite is mainly affected by coalification, maceral composition, moisture content, and seam temperature [2–4]. The formation process of low-rank CBM reservoirs is rather simple, the basin usually experiences only once deposition and then uplift after the formation of the coal seams [1]. If the geological controlling factors, such as basin tectonic, coal-forming environment, and hydrogeology, are matched well, a highly productive CBM zone will form. However, knowing that the CBM zone is highly productive does not, in itself, provide enough information on the geological conditions for CBM mining and on the key issue of recoverability. Reservoir sensitivity is related to the reconstruction of the coal reservoir. Based on sensitivity evaluation, the potential reservoir damage (velocity sensitivity, water sensitivity, acid sensitivity, and so on) can be predicted, and its origins and extent can be determined. Subsequently, targeted measures to improve the reservoir may be put forward. Therefore, a sensitivity evaluation is an important procedure to determine the gas recoverability of lignite reservoirs.

Reservoir sensitivity includes velocity sensitivity, water sensitivity, salt sensitivity, alkali sensitivity, and acid sensitivity [5]. In recent years, the damage and protection of coal reservoirs have received considerable attention from local and foreign researchers, and some

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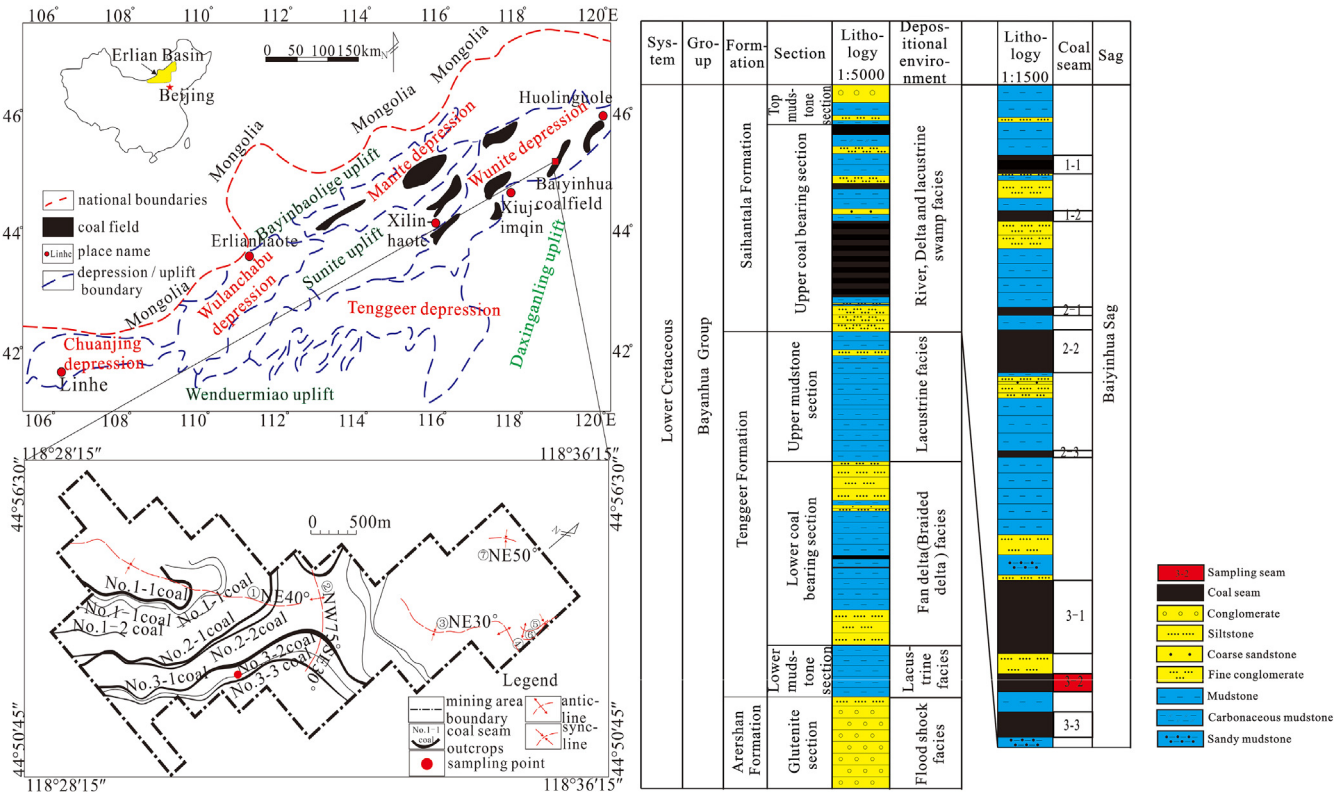

Fig. 1. Sampling locations and coal stratigraphy.

achievements have been made [6,7]. However, their research mainly focused on the stress sensitivity of coal reservoirs and the damage by drilling and fracturing fluid to coal reservoir permeability [8–10]. Few studies have been conducted on velocity sensitivity. Coal seam is characterized by significant brittleness, low compressive strength, and weak consolidation, and a large number of pulverized coal particles with an average particle size of less than 50 μm are easy to produce during drilling or production operations [11–13]. When the wetting fluid velocity exceeds a critical value, mineral particles on the hole wall fall off, disperse, become transported, plug the pore throat, and reduce the permeability of the rock [14]. Numerous experiments and field studies have shown that the dispersed migration of pulverized coal particles is one of the major factors that seriously decrease the permeability of coal reservoirs during the production process and increase the operational costs [15–17]. Given the above reasons, analyzing the governing equations and mechanism of velocity sensitivity in coal reservoir is important.

Velocity sensitivity prediction mainly depends on two methods, namely, laboratory direct testing and indirect analysis. The researchers [6,18–21] used the former method to analyze the relationship between permeability change and flow velocity to determine the critical flow velocity and evaluate the extent of permeability damage caused by the velocity sensitivity effect. Under constant confining pressure conditions, velocity sensitivity tests were conducted at different injection rates. Although this experimental design can simulate the change in permeability of CBM wells at different drainage rates [6], it cannot determine the change in the effective stress and its influence on the velocity sensitivity effect, and when the displacement experiment is performed with a constant flow rate, the pressure fluctuation is too large in the whole process, and a stable permeability cannot be obtained. Therefore, in this study, a variable injection pressure was used to perform the velocity-sensitive experiment under constant effective stress conditions.

The shedding of particles from the surface of a coal matrix is a prerequisite for the formation of velocity sensitivity effects. In the process of CBM drainage, a change in effective stress will produce pulverized coal. The researchers attempted to explore the critical conditions for large falling coal particles with regard to aspects such as salinity, velocity, pH, and temperature [22–28] and to analyze the influence of the coal reservoir physical properties, the coal mineral composition, and the mineral occurrence mode on the velocity sensitivity [29]. However, their research object was either a sandstone or high rank coal reservoir, and the change of effective stress in the process of CBM production will be a key factor of coal output, that was ignored. Research results on lignite reservoir considering effective stress changes on velocity sensitivity were rarely reported. Compared with the conventional reservoir (such as sandstone reservoir), some investigators [29,30] try to evaluate the sensitivity of nitrogen as a fluid medium instead of liquid; on the other hand, this approach obviously cannot reflect the original reservoir conditions. When a liquid is used to evaluate the sensitivity of the reservoir, the liquid to be injected is prepared in accordance with the evaluation block formation water analysis data; alternatively, the liquid used for this purpose consists of standard brine with the same salinity level as that of the formation water [6,31]. However, it should be noted that during the development of coalbed methane, the influx of external fluids (e.g., drilling fluid and pressure fluid) will cause changes in the properties of the formation water. Therefore, if the injection fluid is configured based exclusively on the original characteristics of the formation water, the effect of different properties of formation water on velocity sensitivity is not considered.

In view of the above reasons, the samples of lignite in the Erlian basin were collected for this study. On the basis of the characteristics of formation water and the buried depth of coal seam in the four major low rank coal basins, the velocity sensitivity experiment was carried out under the condition of constant effective stress. The influence of formation water (pH, salinity) and different depths of formation (effective stress) on velocity sensitivity was analyzed to explore the mechanism of velocity sensitivity effect of lignite reservoir under comprehensive influence factors.