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Evaluation of coalbed methane potential of different reservoirs in western Guizhou and eastern Yunnan, China

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HIGHLIGHTS

- Coal reservoir properties are characterized for coals in the study area.
- CBM potential was evaluated using fuzzy optimization model.
- Coal rank in the study area is a key control for CBM development potential.

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ABSTRACT

The coal and coalbed methane (CBM) resources are abundant in western Guizhou and eastern Yunnan, South China. However, commercial CBM production in this region has not been achieved. Reservoir properties are the prerequisites in determining the possibility of CBM exploration and its development potential. Thus, to help to select the most favorable block and to prioritize CBM development in the study area, a comprehensive program of experimental work has been carried out to study the physical properties of coal reservoirs in different blocks. Experimental results show that the properties of coal reservoir change significantly with respect to coal rank, and the coal rank in the study area is very uneven, with the vitrinite reflectance (R_o) of coal samples ranging from 0.68% to 3.31%. In detail, low rank coals have well developed seepage pores but undeveloped adsorption pores, resulting in the low adsorption capacity and high porosity and permeability. With burial depth increase, the metamorphic degree and compaction degree of coals grow accordingly, as a result pores and fractures are gradually closed under stress, leading to a sharp reduction of porosity and permeability in medium rank coals. However, most of the high rank coals in the study area have experienced a large number of tectonic thermal events, which not only increased the metamorphism degree and adsorption capacity, but also improved the porosity and permeability of the coal reservoirs. Based on experimental results, the CBM potentials of coal reservoirs in different blocks in the study area were evaluated using multi-objective and multi-level fuzzy optimization model, and the most prospective zones for CBM production were suggested.

1. Introduction

Now China attaches an unprecedented importance to the exploration and development of coalbed methane (CBM) due to coal mining safety, greenhouse gas emissions and demand for natural gas [1,2]. However, the CBM development activities in China have an extremely uneven geographical distribution. Most of them are concentrated in North China, especially in the Southern Qinshui Basin where the commercial breakthrough of CBM production has been achieved [3–5]. Western Guizhou and eastern Yunnan, the largest coal-producing region in South China, is rich in coal and CBM resources, and it has been considered to have high potential for CBM recovery [6,7]. Nevertheless, the CBM exploration and development in this region has not reached any commercial breakthroughs. One of the main reasons is the lack of understanding of the coal reservoir heterogeneity that resulted from the complex geological conditions in the study area. Previous studies mainly focused on sedimentary characteristics, tectonic evolution and geological conditions [8–10], however, the maturity evolution of coals and the variety in coal reservoir properties in the study area have not been well reported.

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Nomenclature

A, d	ash (dry basis)	S_T	area of T_2 distribution
CI	consistency index	T_2	transverse relaxation time
CR	random consistency ratio	T_E	echo spacing
E	exinite	T_W	waiting time
FC, ad	fixed carbon (air-dried basis)	V	vitrinite
I	inertinite	V_A	actual value
L	length of the core sample	V_B	bulk volume
M	minerals	V_{BJH}	BJH total pore volume
M, ad	moisture (air-dried basis)	V_N	normalized value
n	order of the matrix	V, daf	volatile (dry, ash free basis)
r	radius of the core sample	W	eigenvector
RI	random consistency index	λ_{max}	maximum eigenvalues
R_o	vitrinite reflectance under oil immersion		
S_{BET}	BET pore surface area		

With different coal ranks, the CBM generation and accumulation processes, as well as coal reservoir physical properties vary significantly [11–13]. It is worth mentioning that the differences in coal reservoirs' physical properties will affect the whole process from CBM accumulation to production. Consequently, evaluation of coal reservoir physical properties is the prerequisite for the determination of the CBM exploration and development potential [14–16]. Based on geological setting analyses of western Guizhou and eastern Yunnan, this research is focused on studying the effects of metamorphism degree on coal reservoir physical properties, and proposing an optimized method using coal reservoir physical properties to evaluate the CBM potential by using the multi-objective and multi-level fuzzy optimization model.

2. Geological setting

Western Guizhou and eastern Yunnan, located in the west of the Yangtze Block, covers an area of approximately 2.58×10^4 km^2. The CBM resource is estimated at $2.2–2.75 \times 10^{12}$ m^3 [9]. The main coal-bearing strata in the study area are Longtan Formation and Changxing Formation of Upper Permian, which were developed in nonmarine, marine–terrestrial transitional and shallow marine environments from west to east [17]. After coal seams deposited in the Late Permian epoch, the area studied in this work underwent the Indosinian, Yanshannian and Himalayan orogeny movements. Not only did the tectonic movements generated a large number of folds and faults but also controlled the distribution patterns of the CBM reservoirs [6,10]. Now the main coal-bearing formations are developed in almost 30 sedimentary basins that with complex anticline and syncline structures, in which, Zhina, Gemudi, Panguan, Enhong and Laochang areas are the target CBM blocks [9].

The evolution degree of coals in western Guizhou and eastern Yunnan fluctuates from bituminous coal to anthracite coal. In addition, the coal rank is high in northeast and southwest, but low in the centre of the study area (Fig. 1). Coal metamorphism in the study area is dominated by the burial history besides later tectonic thermal events. The coalification in the study area can be divided into two stages: the pre-Yanshan period and the Yanshan period. In the pre-Yanshan period, the coalification was mainly evoked by burial metamorphism; while in the Yanshan period, the coalification was primarily caused by tectonic thermal metamorphism. Resulted from the various burial history or tectonic thermal events, different evolution process and physical–chemical structure of coals generated, which in return determined the variation in physical properties of coal reservoirs in western Guizhou and eastern Yunnan [7].

3. Experiments and methods

3.1. Samples collection

A total number of 32 coal samples were collected from underground coal mines in western Guizhou and eastern Yunnan. These samples have basically covered 5 key target CBM production areas, including 8 in Zhina block, 6 in Gemudi block, 7 in Panguan block, 6 in Enhong block and 5 in Laochang block. Moreover, the collected samples also fully account for the main coal seams in the study area.

3.2. Experimental work

To characterize the physical properties of coal reservoirs in western Guizhou and eastern Yunnan, three sets of experiments were performed.

Set-I experiments were the tests including the vitrinite reflectance (R_o) measurement, coal maceral composition test and proximate analysis. R_o measurement and coal maceral analyses were carried out on the same polished specimen using the Leitz MPV-3 photometer microscope with the MPS 60 photo system manufactured by Leitz Company of Germany (following China National Standards GB/T 6948-1998 and GB/T 8899-1998, respectively). Proximate analysis (following China National Standards GB/T 212-2001) was performed for all samples to measure the ash content, moisture content and volatile material content of the coals.

To investigate the difference among the adsorption pore structure and CBM storage capacities of coal reservoirs with different coal ranks, Set-II experiments (including low-temperature N_2 isotherm adsorption/desorption analysis and methane isothermal adsorption measurement) were performed. The low-temperature N_2 isotherm adsorption/desorption analysis was carried out with a modified Micromeritics ASAP-2000 automated surface area analyzer following the Chinese Oil and Gas Industry Standard SY/T 6154-1995. To carry out the low-temperature N_2 isotherm adsorption/desorption experiment, all coal samples were crushed and sieved to the size ranging between 0.23 and 0.45 mm, and then dried at 105 °C for 24 h in a vacuum oven. Each sample was measured under the relative pressure from 0.01 to 1 to obtain the BET pore surface area (S_{BET}), the BJH total pore volume (V_{BJH}), and the pore size distribution. With the intention of analyzing the adsorption capacities of coals, methane adsorption isotherm experiments were performed following the China National Standards GB/T 19,560-2004. Coal samples were crushed and sieved to obtain the particle size of 0.18–0.25 mm, weighing up 100–125 g for moisture-equilibrium treatment. The moisture-equilibrium