Geological Storage Conditions and Potential Analysis of Carbon Dioxide in the High-steep Fold Belt in Eastern Sichuan Basin

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Abstract. Carbon sequestration refers to the technology of capturing carbon and storing it safely instead of directly discharging CO_2 into the atmosphere. Rock salt is a promising CO_2 reservoir, and the underground rock salt structure formed by salt cavern reservoirs in geological history has a natural sealing function. Storing carbon dioxide in salt caves can ensure that carbon dioxide is stably stored underground for a long time. However, at present, there are few studies on carbon sequestration in abandoned salt caves. This study analyses the characteristics of carbonate-evaporite strata in the high fold zone of eastern Sichuan and qualitatively evaluates Triassic carbonate-evaporite layers formed in the depth range of 800-3000 m in various sedimentary basins in Chongqing. A large set of carbonates-evaporites are developed in Chongqing, and the carbonate rocks near evaporites have low porosity and permeability, which can be used as CO_2 storage caprock in salt cavities. Thick evaporated strata can also provide a good cover for CO2 storage in abandoned salt caves, which has great potential space resources.

Key words: Salt cavern reservoirs; carbonate reservoirs; Triassic system; Eastern Sichuan basin

1. Introduction

Carbon dioxide geological storage technology (CCS) is regarded as a direct and effective means to reduce emissions. This technology captures CO_2 originally discharged into the atmosphere and injects it into closed underground reservoirs after treatment, thus reducing the emission of CO_2 into the atmosphere and slowing down air pollution and the greenhouse effect. The ultimate goal of CCS is to isolate CO_2 from the atmosphere for a long time and safely to reduce the concentration of greenhouse gases in the atmosphere. Therefore, CO_2 storage is the most critical link of CCS, and the analysis of storage potential and storage cost of storage sites has become an important part of CCS evaluation. CCS aims at large-scale CO_2 emission reduction. For the early implementation of CCS, from the perspective of saving transportation costs, the storage potential of a storage site should be at least greater than the total emission of a large coal-fired power plant in 20-30 years (40×10^6 t-60×10^6 t); otherwise, CCS is of little significance to greenhouse gas emission reduction. Second, the reservoir is required to be well sealed, that is, the caprock overlying the reservoir is impermeable or extremely low permeability rock, to prevent the injected CO_2 from leaking through the caprock, causing many CCS projects to fail. At present, CCS technology has been widely studied by researchers around the world. Safe storage of CO_2 is the ultimate goal of CCS, and the feasibility of geological storage determines the feasibility of CCS technology.

Under the situation that China's coal-based energy consumption structure is difficult to change in the short term, developing geological storage of carbon dioxide is an effective measure to realize China's carbon emission reduction commitment. In recent years, the geological storage of carbon dioxide has developed rapidly in the fields of regional investigation and evaluation, key technology research and engineering demonstration. The geological utilization and storage technology of carbon dioxide has gradually become a system, but it is still in the demonstration research stage. It is of great significance for the planning and implementation of carbon capture, utilization and storage in China to continue the investigation and evaluation of carbon dioxide geological storage and innovate the technical methods. It has been less than 10 years since China achieved the peak carbon dioxide emissions goal, and only 30 years since peak carbon dioxide emissions achieved the goal of carbon neutrality. Compared with developed countries, it is shorter, more extensive, more difficult and extremely

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arduous to achieve the long-term goal of peak carbon dioxide emissions and carbon neutrality. Chongqing's emission sources are mainly concentrated in the cement and thermal power industries. Based on the actual situation in Chongqing, the total amount of coal decreased during the 14th Five-Year Plan period, and the process of low-carbon transformation gradually accelerated. Using the evaluation index system and evaluation technology method of carbon dioxide geological storage potential and suitability established in China, the potential and suitability of carbon dioxide geological storage in the eastern Sichuan Basin were evaluated. This study focuses on eastern Sichuan basin and discusses the carbon sequestration potential of Triassic carbonates-evaporite strata in the Dianjiang salt basin.

2. Geological settings

The eastern part of the Sichuan Basin is a large-scale continental clastic sedimentary basin that contains oil, gas, salt and brine. The reservoir types of oil and gas are mainly fluvial delta facies and shore-shallow lake facies sand bodies. Rock types are mainly carbonate rock, shales and evaporites. Generally, these evaporated rocks have good physical properties and good traps, which is a potential reservoir basin in which the Jialingjiang Formation has the potential for sealing and is also a continental sedimentary basin with high salinity. One basin in Sichuan and Chongqing is larger than 100,000 km^2, one in 100,000-10,000 km^2, two in 100,000-100,000 $km^2$and five in less than 100,000 km^2. The gypsum salt deposits of the Jialingjiang Formation are mainly located in the eastern Sichuan Basin, including Wanzhou, Zhongxian, Liangping, Dianjiang, Changshou, Yubei, Jiangjin, Hechuan and Yunyang. There are 3 known salt basins (Shilong at Jiangjin, Baziyan atYubei and Dianjiang) and 1-30 layers of gypsum and halite, which is one of the important salt-forming periods in China.

3. Samples and analysis

Ten samples of carbonate rock, gypsum salt and rock salt from the Jialingjiang Formation drilled in the Dianjiang Salt Basin were selected for porosity and permeability experiments. The reference standard of experimental method is GB/T 29172-2012.

4. Results

The porosity of samples from the Jialingjiang Formation a drilling-core in the Dianjiang area are 0.63%-2.56%. The permeability of the samples are 0.0006-0.0018^{-3} μm^2.

Table 1. The porosity of samples from the Jialingjiang Formation a drilling-core in the Dianjiang area are 0.63%-2.56%. The permeability of the samples are 0.0006-0.0018^{-3} μm^2.

No.	Sample.No.	Sample state	Effective porosity %	Permeability×10^{-3} μm^2
1	Y230982001	cylindrical	1.69	0.001
2	Y230982002	cylindrical	2.56	0.0007
3	Y230982003	cylindrical	1.63	0.0007
4	Y230982004	cylindrical	0.91	0.0013
5	Y230982005	cylindrical	1.44	0.0013
6	Y230982006	cylindrical	1.23	0.0018
7	Y230982007	cylindrical	0.63	0.0011
8	Y230982008	cylindrical	2.08	0.001
9	Y230982009	cylindrical	1.28	0.0009
10	Y230982010	cylindrical	1.48	0.0006

5. Evaluation of sealing conditions of the high-steep fold belt in eastern Sichuan

5.1 CO_2 geological storage in the deep part of eastern Sichuan.

Carbon sequestration in carbonate rocks. The CO_2 in eastern Sichuan is sealed in structure or geology and pores. Structural or stratigraphic sealing mainly means that the upper caprock or reservoir blocks the upwards passage of CO_2 and prevents CO_2 from escaping. Pore sealing mainly means that CO_2 displaces the existing fluid to occupy and fill the pores in the rock, and the capture provided by capillary force can leave CO_2 in the pores of the reservoir structure. There are many gas fields in Chongqing, such as the Wolonghe gas field. The gypsum and salt deposits in the Jialingjiang Formation are generally divided into four sections, of which the first and third sections are mainly limestone and dolomitic limestone. The second and fourth members are dolomite and salt-dissolved breccia (gypsum-salt layer). When the fifth members of the Jialingjiang Formation and Leikoupo Formation remain, they may still be important gypsum and salt horizons. The formation temperature of the Triassic Jialingjiang Formation in the Sichuan Basin is relatively stable, basically maintained at 3℃/100 m; that is, the burial depth reaches 3000 m, which is the key depth for brittle-plastic transformation of gypsum rock of Jialingjiang Formation in the Sichuan Basin. Through the study of the burial history of the Sichuan Basin, it is found that during the Cretaceous sedimentary period, the burial thickness of Triassic strata in the Sichuan Basin reached approximately 3000 m, and the formation temperature reached 100°C. Gypsum rock has changed from brittle to plastic, sealing faults and fractures in the formation and improving sealing performance, which provides favorable conditions for carbon dioxide storage in Triassic carbonate-evaporite strata in the study area.

After CO_2 is injected into the ground, a phase equilibrium reaction occurs, which reduces the pH value of the formation water (Bachu et al.,2003). The diffusion coefficient of supercritical carbon dioxide is much higher than that of liquid carbon dioxide. When the pressure is

lower than the critical pressure, the diffusion coefficient of carbon dioxide decreases rapidly with increasing pressure. When the pressure is higher, the pressure has relatively little effect on the diffusion coefficient of carbon dioxide. This will change the balance between the original salt water and rocks in the formation, leading to mineral dissolution or precipitation in the formation. The reaction of minerals in the brackish water layer of carbonate rocks is relatively simple; calcite, dolomite and other carbonate minerals are mainly dissolved, and secondary carbonate minerals such as ankerite and siderite are difficult to generate because there are no silicon-aluminum minerals to provide related ions such as Ca^{2+}, Fe^{2+} and Mg^{2+}(Cinar et al.2007).

Salt cavity is a potential carbon sequestration geologic body. The abandoned solution cavity formed by brine mining is an available underground space resource . Salt rock is a mineral aggregate composed of rock salt, and its main component is NaCl, which is a soluble evaporite minerals. The strata of the Jialingjiang Formation and Leikoupo Formation contain a large set of salt rocks with compact structure, low porosity and low permeability, which have good rheological properties. Salt rock is mainly mined by water solution and has self-healing characteristics (Liu et al.,2016), so it is recognized by scholars as the most suitable geological body for underground CO_2 geological storage(Kopp et al.,2009). The waste salt cavity may contain brine or salt water, which can be used as a good medium for CO_2 storage (Kumar et al.,2005). According to the achievements of the UK-China Prosperity Strategic Fund project "Geological Utilization and Storage Potential of Carbon Dioxide in Sichuan Basin and Early Demonstration Opportunities", the storage potential of Chongqing's CO_2 saline aquifer is 745 million tons. By the end of 2018, 11 rock salt mines had been discovered in the Chongqing city, including 7 rock salt mines and 4 bitterns. At present, the main salt mines in use are the Changshou Shuanglong Salt Mine and Hechuan Dashi Salt Mine, and the rest of the abandoned salt mines can be used as the objects of prestorage selection and evaluation.

5.2 Influence of faults on CO_2 storage

The basic geological conditions, such as porosity and permeability, of geological bodies around salt caves should be evaluated in the assessment of carbon dioxide storage in Chongqing. When CO_2 is injected into the fault, the pore pressure near it will increase, which will lead to the revival of the fault and the destruction of the caprock. The leakage of CO_2 along faults/fractures is mainly affected by the fracture opening and effective permeability. CO_2 leaks and migrates back to the atmosphere through faults, which provide potential leakage channels, leading to the pollution of the aquifer above the caprock. When a CO_2 salt cavern is sealed and located, it is necessary to determine the distribution of faults in this area by geophysical means and try to avoid unfavorable factors in the cavity-building area.

5.3 Effect of temperature on CO_2 storage

Study on the influence of temperature on geological storage of CO_2, including formation temperature and injection temperature. CO_2 becomes a supercritical fluid in the deep stratum, and its viscosity is only approximately one order of magnitude higher than that of atmospheric gas and much lower than that of liquid. Supercritical CO_2 has excellent mass transfer capacity. Higher temperatures will greatly reduce the fluid density, thus increasing the buoyancy in CO_2. The temperature change has a significant effect on the solubility of CO_2 in deep saline aquifers. Higher temperature leads to a great decrease in fluid density, which increases the buoyancy of CO_2, reduces the viscosity and increases the fluidity of CO_2. With increasing temperature, the diffusion coefficient of carbon dioxide also increases. With increasing pressure, the viscosity of carbon dioxide increases.

6. Conclusion

Carrying out carbon sequestration in Chongqing is conducive to the foundation of subsequent carbon neutralization, and geology comes first. CO_2 geological storage is the most direct and reliable method that can effectively reduce emissions. It is urgent to carry out scientific exploration on the influence of complex factors on the efficiency and safety of CO_2 geological storage. The factors that affect the storage capacity of CO_2 are the stratum structure (stratum dip), faults, lithology, thickness and porosity and permeability characteristics of the rock mass, salinity, temperature and pressure of deep groundwater, and injection temperature, which can be controlled by the outside world. Based on the comprehensive analysis of the regional geological background and the evolution characteristics of lithofacies and palaeogeography in the basin, the CO_2 covering the eastern Sichuan Basin was constructed.Abandoned salt caverns will be the primary underground storage space of choice for carbon sequestration in Chongqing

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