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Possibilities and potentials of geological co-storage CO₂ and SO₂ in China

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Abstract

Carbon capture and storage (CCS) is widely accepted as one of main solutions to mitigate global warming in the world. However, the still-high cost of CCS is one of the major concerns, in particular in developing China. In the other hand, emission control of H₂S and SO₂ has already become the urgent need, and the reduction target has been set in the 11th Five-Year Plan of China. Therefore, co-storage of CO₂+SO₂ or CO₂+H₂S may be an effective way to reduce CCS cost, e.g. due to saving the desulphur device, and enable CCS to has an earlier deployment opportunity.

In this paper, we try to, at first, reveal some key problems, i.e., trapping mechanism, injectivity and leakage risk, for co-injection and co-storage of CO₂ and the strong acid SO₂ into subsurface spaces in a certain gas field in China. The output of this gas field includes about 6.8% H₂S and 4.6% CO₂. Then, we want to insight into the possibilities and potentials of co-storage of CO₂+SO₂ by numerical studies. After widely referring all opened and published scientific and technical literature, we develop a model to study a porous media system associated with the thermo-hydro-chemical coupling interactions. The hydrogeology and mineralogy of the injected formation are extracted from the historical materials of the gas field. We have performed several numerical simulations with consideration of a sandstone-clay sequence under acid-gas injection conditions. The clay formation is supposed as a sealed cap rock for the co-storage disposal system. The study examines the impact of SO₂ co-injection on the pH of formation brine. Co-injection of CO₂ with SO₂ results in a larger and more strongly acidified zone, and alteration differs substantially from that caused by the injection of CO₂ alone. The mineral alteration induced by injection of CO₂ with SO₂ leads to corresponding changes in porosity. Significant increases in porosity occur in the acidified zones where mineral dissolution dominates.

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Keywords: Acid gas, CCS, H₂S, SO₂, SCCS, numerical simulations, potential site

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1. Introduction

Carbon dioxide (CO₂) Capture and Storage (CCS) in some possible geological reservoirs has been identified as important options for reducing anthropogenic greenhouse gas (GHG) emissions to offset global warming. However, the still-high cost of CCS is one of the major difficulties to allure the participation from the industry, and this also leads to negative actions of worldwide countries when moving beyond Kyoto. As known, USA and China are two major carbon emission sources in the world. China governments have put some funds for CCS. Some demonstration projects, e.g. Shenhua Ordos, are also being conducted to verify the possibilities of geological sequestration of CO₂ into saline aquifers, depleted oil/gas reservoirs, and coal-beds in China. On the other hand, emission control of H₂S and SO₂ has already become the urgent need during the development in China, and the reduction target has been set in the 11th Five-Year (2005-2010) Plan of China. Therefore, co-storage of CO₂+SO₂ or CO₂+H₂S may be an effective way to reduce CCS cost, e.g. due to saving the de-sulphur device, and enable CCS to have an earlier deployment opportunity [1]. In the regime of co-storage, an understanding of the direction, rate, and magnitude of geochemical reactions is great important to evaluate storage capacity and injectivity of potential reservoirs. Such investigations ensure the operational aspects of co-storage into possible formations over a long period of time [2].

In order to implement the co-storage of CO₂+SO₂ or CO₂+H₂S, we termed Sulfur and Carbon Co-Storage (SCCS), some key problems, i.e., trapping mechanism, injectivity and leakage risk should be revealed. In particular, the issues of SCCS other than CCS such as the erosion of the strong acid SO₂ gas into subsurface spaces are needed to be thoroughly investigated. Although SCCS may raise some technical renovation in China, the injection of acid gases, such as CO₂ and H₂S mixture, into the subsurface environment has a long history, especially in western Canada [3]. After a wide review of all opened techniques and published literature. e.g., [4-11], a numerical model for waste disposal, such as GHG and HLW, is developed to study a porous media system associated with the thermo-hydro-mechanical-biogeochemical coupling interactions [12]. A potential co-injection site in western China is addressed in this paper. We have performed several numerical simulations using one/two dimensional (1-D/2-D) models with consideration of a sandstone-clay sequence under acid-gas injection conditions. The study examines the impact of SO₂ co-injection with CO₂ on the pH of formation brine. Co-injection of CO₂ with SO₂ results in a larger and more strongly acidified zone, and alteration differs substantially from that caused by the injection of CO₂ only. The mineral alteration induced by injection of CO₂ with SO₂ leads to corresponding changes in porosity. Significant increases in porosity occur in the acidified zones where mineral dissolution dominates. The main conclusion is that saline acidification due to co-injection of SO₂ with CO₂ is likely to be significant over relevant short geological time, e.g. 1000 years and spatial scales for the proposed site aquifers.

2. Site and modeling

2.1 Potential site

There are many near depleted gas field in western China. According to our investigation and collected data, most of them provides potential for the SCCS. In figure 1, the basin contours of a certain potential site are plotted. This gas field locates in Triassic formations with depth of 3140~3510m. The output of gases includes about 6.8% H₂S and 4.6% CO₂. Then, we want to insight into the possibilities and potentials of co-storage of CO₂+SO₂ by numerical studies at the development stage. The hydrogeology and mineralogy of the injected formation are extracted from the historical materials of the gas field in China. The clay formation is supposed as a sealed cap rock for the co-storage disposal system.

2.2 Geometrical setup

The potential storage formation is assumed to be infinite and homogeneous with a thickness 100 m. The 2-D model is adopted for the sandstone-clay formation sequence. The 1-D model is used to simulate the radial reactive flow of injected acid gases in the storage formation (Figure 2). The basic hydrogeological parameters for this model are listed in Table 1. Hereafter, only results of 1-D radial reactive flow model are addressed.

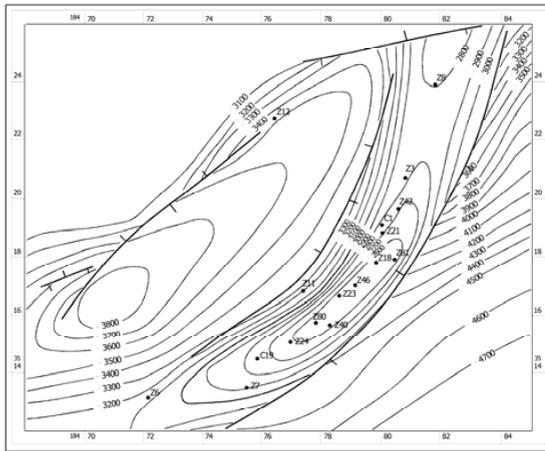


Figure 1. Basin contours of a potential site for co-storage of CO₂ with SO₂ in western China.

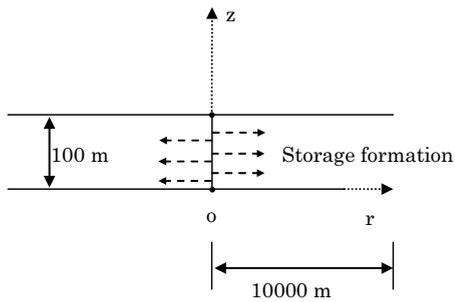


Figure 2. 1-D radial model for acid gas injection.

Table 1. Hydrogeological parameters for acid gas injection

Parameters	Values
Porosity [-]	0.2
Permeability [m ²]	1x10 ⁻¹⁵
Diffusivity [m ² /s]	1x10 ⁻⁹
Bulk density [kg/m ³]	2600
Injection rate of CO ₂ [kg/s]	1.0

2.3 Computational setup

The two injection cases were considered, i.e. CO₂ only and CO₂ plus SO₂. The injection operates for a period of 100 years, and the total simulation time is 1000 years. In this paper, the ToughReact is adopted as the external reactive solver. The ECO2N module used in ToughReact considers only three components, i.e. water, brine, and supercritical CO₂. Therefore, Co-injection of SO₂ can be processed separately into the brine as incorporated gas. The primary and possible secondary minerals composition was listed in Table 2.

Table 2. Initial and possible secondary mineral composition in the reactive simulations

Mineral	Formula
<i>Primary:</i>	
Quartz	SiO ₂
Calcite	CaCO ₃
Kaolinite	Al ₂ Si ₂ O ₅ (OH) ₄
Illite	K _{0.6} Mg _{0.25} Al _{1.8} (Al _{0.5} Si _{3.5} O ₁₀)(OH) ₂
Chlorite	Mg _{2.5} Fe _{2.5} Al ₂ Si ₃ O ₁₀ (OH) ₈
K-feldspar	KAlSi ₃ O ₈
Oligoclase	Ca _{0.2} Na _{0.8} Al _{1.2} Si _{2.8} O ₈
Na-smectite	Na _{0.29} Mg _{0.26} Al _{1.77} Si _{3.97} O ₁₀ (OH) ₂
Hematite	Fe ₂ O ₃
<i>Secondary:</i>	
Anhydrite	CaSO ₄
Magnesite	MgCO ₃
Dolomite	CaMg(CO ₃) ₂
Pyrite	FeS ₂
Ankerite	CaMg _{0.3} Fe _{0.7} (CO ₃) ₂
Dawsonite	NaAlCO ₃ (OH) ₂
Siderite	FeCO ₃
Alunite	KAl ₃ (OH) ₆ (SO ₄) ₂
Low-albite	NaAlSi ₃ O ₈
Ca-smectite	Na _{0.145} Mg _{0.26} Al _{1.77} Si _{3.97} O ₁₀ (OH) ₂

3. Results and discussion

Figure 3 plots the change of pH values around the injection well at two different times. The pattern is similar for the two different co-injection cases of acid gases. Corrosion is one of issue to cause the lower pH, in particular close to the injection well. The dissolution of chlorite and the precipitation of ankerite occur near the borehole, even after the injection stops (Figure 4). The significant CO₂ is trapped in ankerite. The dissolution and/or precipitation of mineral phases in storage formations results in change of porosity (Figure 5). In particular, the significant increase of porosity occurs close to the well region for the co-injection case of CO₂+SO₂.

The future research includes the parametric studies of typical aquifer characteristics, such as heterogeneity, dip angle, vertical to horizontal permeability ratio, and purity of SO₂, so as to determine their effect on co-injection and co-storage potential of a CO₂+SO₂ mixture. We hope our study can inspire and convince the CCS scientists and governmental officers to recognize the co-injection and co-storage of CO₂ with SO₂ into deep geologic formations

are possible and potential, especially less expensive or less energy, to greatly reduce atmospheric emissions of acid gases in developing China.

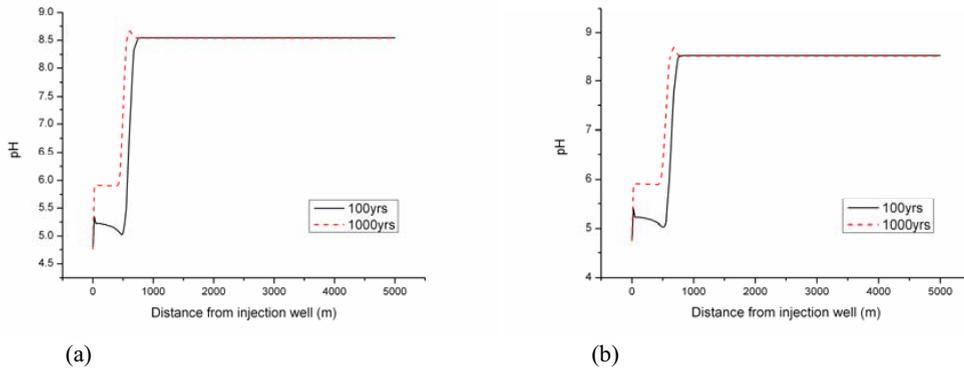


Figure 3. pH at different times along the radial distance. (a) CO₂ (b) CO₂+SO₂

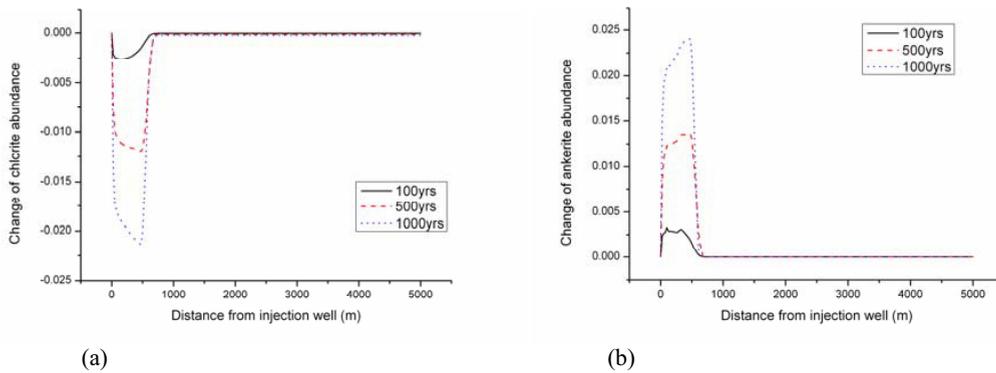


Figure 4. Change of chlorite and ankerite abundances at different times for the co-injection case of CO₂+SO₂.

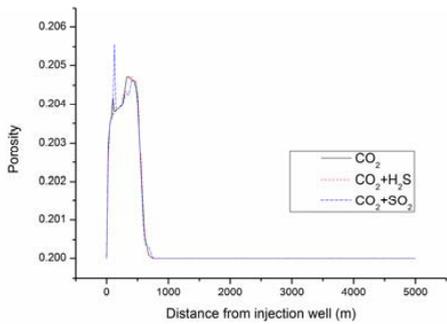


Figure 5. Porosity change around the injection well under different co-injection cases.

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