Feasibility of the combination of CO\textsubscript{2} geological storage and saline water development in sedimentary basins of China

Qi Li\textsuperscript{a,*}, Ya-Ni Wei\textsuperscript{a}, Guizhen Liu\textsuperscript{a}, Miao Jing\textsuperscript{a}, Min Zhang\textsuperscript{a}, Wenbin Fei\textsuperscript{a}, Xiaying Li\textsuperscript{a}

\textsuperscript{a}State Key Laboratory of Geomechanics and Geotechnical Engineering (SKLGME), IRSM, Chinese Academy of Sciences, Wuhan 430071, China

Abstract

Utilization plays a key role in the deployment of CCS in China. CO\textsubscript{2} geological storage and utilization (CGSU) shows most charming potential for carbon mitigation in China according to the technology roadmap study of carbon capture, utilization, and storage (CCUS) in China. After a general review and a thorough investigation, the partition of China mainland into three CCUS zones is figured out mainly according to the different types of aquifer systems. Focusing on coal chemical enterprises in the western China (Zone I), a novel CGSU method is proposed in this paper. By CO\textsubscript{2} enhanced recovery of deep saline water, a tripartite win system is charming promotion of China western development. The cross point of the developed system is to attract investment on coal chemical industry to use local rich coal resources, to meet great water demand of coal chemical industry in the water shortage of China western region, and to maximum optimize of pressure buildup of CO\textsubscript{2} geological storage.

Keywords: CO\textsubscript{2} geological storage and utilization (CGSU); CO\textsubscript{2}-EWR; Northwest China; Coal Chemical Industry.

1. Background

* Corresponding author. Tel.: +86-27-87198126; fax: +86-27-87198967.
E-mail address: qli@whrsm.ac.cn.
Carbon dioxide (CO₂) Capture and Storage (CCS) is a promising contribution to reduce further increase of atmospheric CO₂ emissions from fossil fuels. The CCS concept anticipates that large amounts of CO₂ are going to be stored in the subsurface for the long term [1].

Three storage options, i.e. uneconomic coal beds, oil and gas reservoirs and deep saline formations, have been identified to have the potential to sequester CO₂ in the short to medium term. All these storage options have the capacity (porosity) and injectivity (permeability) necessary for CO₂ injection, and geological time to prevent and delay CO₂ return to the atmosphere. Of these three options, deep saline formations possess the largest CO₂ storage capacity, besides having the advantage that they are present also in regions where there are no oil and gas reservoirs or where oil and gas reservoirs are still in production and are not yet available for CO₂ storage [1, 2].

It’s confirmed that sedimentary basins contain suitable geologic media for CO₂ storage. Fortunately and serendipitously, sedimentary basins are also where fossil energy resources are found, produced and, by and large, used for power generation or coal chemistry with large quantity CO₂ emissions and industrial water needed.

Utilization is a national choice in the deployment of carbon mitigation in China according to China technology roadmap study of carbon capture, utilization, and storage (CCUS) [3]. According to different types of aquifer systems, sedimentary types of reservoirs, and other factors, the partition of China mainland into three CCUS zones is figured out (Fig. 1). Different CO₂ geological utilization can be expected in different zones. For example, simultaneous mineralization of CO₂ and recovery of soluble potassium are to be expected in Sichuan Basin (Zone III) [4], and the mitigation of subsidence induced by over withdrawal of ground water in North China and Su-Xi-Chang region is to be investigated by regulation of pressure buildup of CO₂ geological storage (Zone II) [5, 6].

Saline formations represent a vast storage resource, and the waters they contain could be managed for beneficial use [7]. To address this issue of CO₂ geological storage and utilization (CGSU) [8], the evaluation of the feasibility of deep saline formations for CO₂ storage, and extracting and treating saline waters for industrial use in China western region (Zone I) are carried out in this paper.

As known, the CCS chain is great water demand. The need of water mainly comes from the capture process. The amount of water demand varies very depending on the choice of different capture methods [9, 10]. In particular, for the coal chemical industry itself, it needs great water for production process. Table 1 lists water demand and CO₂ emission per unit of product of China’s coal chemical industry. The amazing amount can be imagined if coal chemical enterprises adopts great water demand capture module for the future implementation of CCUS in China.

| Product               | Water Demand per Unit of Product (ton/ton) | CO₂ emission per Unit of Product (ton/ton) |
|-----------------------|-------------------------------------------|-------------------------------------------|
| Ammonia               | 21.60                                     | 4.04                                      |
| Methanol              | 8.50                                      | 3.16                                      |
| Dimethyl ether        | 7.20                                      | 4.44                                      |
| Direct liquefaction   | 12.00                                     | 2.90                                      |
| Indirect liquefaction | 13.00                                     | 7.22                                      |
Fig. 1. Major Aquifers in China Mainland [Courtesy of China Geological Survey].
2. CO₂-Enhanced saline Water Recovery (CO₂-EWR) System

The comprehensive analysis of the combination of CO₂ storage and saline water development in all major sedimentary basins of China includes four sub-modules according to the analysis of the whole chain from CO₂ emission to storage (Fig. 2): 1) Plant Module (Plant types, production, CO₂ emissions, water quality and quantity demand); 2) CO₂ Capture Module (rate, carbon capture and compression costs, water demand); 3) CO₂ Sequestration Module (transport and sequestration costs, the injection impact on the geochemistry, injection rate, CO₂ plume migration law); 4) Extracted Water Module (unit CO₂ displaces saline water, mining wells impact on the seal, capacity and depress under extraction, extracted water capacity and quality, water production transport and treatment costs). Brines up to 85,000 ppm total dissolved solids produced during CCS operations in saline formations may be used as the feedstock for desalination and water treatment technologies via reverse osmosis [11]. The aquifer pressure resulting from the injection of CO₂ can provide all or part of the inlet pressure for the desalination system.

A study of hypothetical power plant and saline formation in the south-western United States indicates a high efficiency reverse osmosis system shows promise for economical desalination at the volumes of recovered water under consideration. The results indicate a CO₂-EWR system may be feasible for tens to hundreds of years [7].

According to the mineralization degree, ground water is classified into five types (China GB/T 14157-93) which is listed in Table 2. The possibility and ability of the extracted water meet the need of the plants were evaluated throughout all major sedimentary basins in China. The proposed types of saline water for recovery in China lies into the range of (3..50).

Table 2. Classification of ground water according to the total dissolved solids in China.

| Ground water   | Fresh water | Weak saline water | Medium saline water | Strong saline water | Brine   |
|---------------|-------------|-------------------|---------------------|---------------------|---------|
| TDS* (g/L)    | Less than 1 | 1-3               | 3-10                | 10-50               | More than 50 |

*TDS: Total Dissolved Solids.

Fig. 2. CO₂-EWR System.
3. Projection in China Western Region

Table 3 listed the major sedimentary basins in Xinjiang, China. The methodology addressed aforementioned was applied to assess all major sedimentary basins in Xinjiang, China. The positioning of the CO$_2$-EWR system is to focus on the recovery of saline water from the deep (more than 800 m) aquifers when geologically storing CO$_2$ captured from coal chemical enterprises in China western region.

Table 3. Major sedimentary basins in Xinjiang, China.

| Xinjiang          | Area (km$^2$) | Thickness of sedimentary rock (m) | Perimeter (km) | Geologic period |
|-------------------|---------------|-----------------------------------|----------------|-----------------|
| Junggar basin     | 158240        | 12000-13000                       | 25.387         | C-P, T-N        |
| Tarim Basin       | 596600        | 17000-21000                       | 41.057         | P, T$_1$-N      |
| Turpan-Hami Basin | 55810         | 8000-9000                         | 19.798         | C-P, T-N        |

The charming points of the developed system are to attract investment on coal chemical industry to use local rich coal resources, to meet great water demand of coal chemical industry in the water shortage of China western region, and to maximum optimize of pressure buildup of CO$_2$ geological storage.

A three-dimensional simulation domain, as seen in Fig. 3, is selected to represent a 100m thick reservoir at a depth of more than 800 m. While the top and bottom boundaries are kept impermeable. The supercritical CO$_2$ is injected at a constant rate of 1Mt/a. The saline water extraction rate is 10,600 m$^3$/d. Fig. 4 shows the comparison of pressure of the monitoring point for the cases with and without saline water pumping. It can be seen that saline water extraction readily helps to reduce the peak overpressure, and this is positive for large amount of CO$_2$ geological storage. The preliminary study also shows that the feasibility of the combination of CO$_2$ storage and saline water recovery is high basin specific in China.

![Fig. 3. Computational domain in preliminary numerical analysis.](image)
4. Conclusions

Different types of CO2 geological utilization are to be expected in different regions in China. China mainland is figured out three zones for CCUS mainly according to the different types of aquifer systems.

Targeting on coal chemical enterprises in China western region, a CO2-enhanced saline water recovery (CO2-EWR) System is proposed for tripartite win. It is very charming not only for China western development, but also for similar situation of Inner Mongolia.

Acknowledgements

QL is supported by the Hundred Talent Program of Chinese Academy of Sciences. We acknowledge Dr. Peng Sizhen and Dr. Zhang Jiutian of ACCA21 for their meaningful suggestions and encouragement.

References

[1] Metz B, Davidson O, de Coninck H, Loos M, Meyer L, editors. IPCC 2005: IPCC Special Report on Carbon Dioxide Capture and Storage. Cambridge, UK: Cambridge University Press; 2005.
[2] Li Q, Li X, Du L, Liu G, Liu X, Wei N. Potential Sites and Early Opportunities of Acid Gas Re-injection in China. In: Wu Y, Carroll JJ, Zhu W, editors. Sour Gas and Related Technologies. New York: Wiley Scrivener; 2012, p. 131-40.
[3] ACCA21. Technology Roadmap Study: Carbon Capture, Utilization, and Storage (CCUS) in China. Beijing, China: ACCA21; 2011.
[4] Xie H, Wang Y, Ju Y, Liang B, Zhu J, Zhang R, et al. Simultaneous Mineralization of CO2 and Recovery of Soluble Potassium using Earth-abundant Potassium Feldspar. Chinese Sci Bull 2012 2012/09/01:1-5.
[5] Li Q, Ito K, Dong Y, Sato I, Seki Y, Tomishima Y, et al. PS-InSAR Monitoring and Finite Element Simulation of Geomechanical and Hydrogeological Responses in Sedimentary Formations. 2011 IEEE International Geoscience and Remote Sensing Symposium (IGARSS). Vancouver, BC, Canada: IEEE 2011;2193 - 6.
[6] Li Q, Ito K. Numerical Analysis and Modeling of Coupled Thermo-Hydro-Mechanical (THM) Phenomena in Double Porous Media. In: Laughton RH, editor. Aquifers: Formation, Transport and Pollution. New York: Nova Science Publishers; 2010, p. 403-13.
[7] Kobos PH, Cappelle MA, Krumhansl JL, Dewers TA, McNemar A, Borns DJ. Combining power plant water needs and carbon dioxide storage using saline formations: Implications for carbon dioxide and water management policies. *Int J Greenhouse Gas Control* 2011;5(4):899-910.

[8] Li Q. CO2 Enhanced Saline Water Recovery (CO2-EsWR). In: ACCA21, editor. *Training School of China Australia Geologcial Storage of CO2 (CAGS)*. Beijing, China 2012;1-33.

[9] Mancuso L, Cotone P. Water Usage and Loss of Power in Power Plants with CO2 Capture. *2010 EPRI Advanced Coal & CO2 Capture & Storage Seminar*. Rome, Italy 2010.

[10] Delgado A, Herzog HJ. *Simple Model to Help Understand Water Use at Power Plants*. Cambridge, MA: Massachusetts Institute of Technology; 2012.

[11] Wolery T, Aines R, Hao Y, Bourcier W, Wolfe T, Haussman C. *Fresh Water Generation from Aquifer-Pressured Carbon Storage*. Livermore, CA: Lawrence Livermore National Laboratory; 2009 2009 Nov 25.