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Improvement of Environmental Monitoring Technology on the basis of Carbon Mass Balance during CO_2-enhanced Oil Recovery and Storage

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Abstract

This study reviewed the emission inventory of carbon injection, production, storage, and emission. Results indicated that only approximately 95% of injected CO_2 can be measured. Approximately 92% to 95% of carbon was stored, 0.01% was leaked from soil, and the residual 5% may have come from leak paths or may have leaked from near-surface sources, such as underground water, through biological metabolism. To develop a carbon mass balance model for CO_2 enhanced oil recovery projects, the emission part from soil and underground water, as well as the fixation by vegetation, should be carefully measured. The residual 5% that remains unmeasured should be proven, i.e., whether such amount is derived along leak paths or is emitted from near-surface sources. Findings could highlight the fate of carbon, provide some suggestions to guide the selection of environmental monitoring technology, and aid in establishing a common methodology to identify leak risks for carbon storage projects.

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Keywords: mass balance; CO_2; enhanced oil recovery; environmental monitoring

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1. Introduction

The potential value of CO_2 enhanced oil recovery (CO_2-EOR) has been highlighted as a win–win relationship among greenhouse gas mitigation, energy security, and the economy. However, CO_2-EOR is confronted by numerous problems worldwide. These problems include high cost, high energy penalty, and uncertainty over long-term safety and reliability. Effectively addressing such problems and improving the technical readiness of CO_2-EOR are common challenges. Developed countries, including Europe, Australia, the United States, Japan, and the United Kingdom, have provided regulations for carbon storage and emphasized the importance of environmental impacts during the life cycle of CO_2 storage [1]. In China, CO_2-EOR remains in the early research stage (development and demonstration phase), and existing CO_2-EOR projects focus mainly on oil recovery efficiency. Thus, no proposal or regulation of environmental impact assessment exists for CO_2-EOR in China.

The International Energy Agency Greenhouse Gas R&D Program has facilitated numerous works on CO_2-EOR. This organization has sponsored "the monitoring selection tool-Interactive Design of Monitoring Programs for the Geological Storage of CO_2" [2]. This tool is helpful for oil companies to conduct environmental impact assessment during the CO_2-EOR process. However, no common methodology exists for environmental monitoring and impact assessment for CO_2-EOR. This condition may be attributed to several reasons. First, environmental monitoring during CO_2-EOR involves multiple research fields, including environmental engineering, geological engineering, power engineering and engineering thermo-physics, geotechnics, and hydraulic engineering. The methodology for environmental monitoring and impact assessment require collaboration. Second, different CO_2-EOR projects, such as reservoir, geology, and surrounding environment (the density of population and industry distribution) possess special characterizations. To improve the development of environment monitoring methodology, the efficiency in determining the leakage risk and the cost for environmental monitoring are key factors. The stored and leaked parts of CO_2 are generally assumed to be indicators for assessing the environmental and social benefits of projects. The primary difference between CO_2-EOR and pure CO_2 storage is that CO_2 could be reproduced during oil production. This part of CO_2 is normally re-injected into a reservoir or directly vented. However, limited research has quantified CO_2 distribution during CO_2-EOR.

This study determines the part of CO_2 that should mainly be measured on the basis of carbon mass balance by reviewing monitored EOR projects. The feasibility of environmental monitoring technologies is also discussed.

2. CO_2 mass balance model

Carbon mass balance, which is based on the physical reality that input injection must be balanced with fluid output during CO_2-EOR, should be investigated to screen the core monitoring technology and the accuracy of monitoring equipment. A CO_2 mass balance model is constructed according to the research of Leach [3].When CO_2 is injected into a reservoir, some part of it can be produced with oil. The produced CO_2 could be vented or recycled. If all the produced CO_2 is recycled, the total CO_2 injection is the sum of new purchases, recycled CO_2, and final emissions (across intermediate media, such as underground water, soil, ground water, and vegetation) into the atmosphere. When the carbon mass balance or the distribution of each part is determined, the core monitoring object can be known. Thus, the accuracy and range could be confirmed. According to the results of carbon balance, the quantity of CO_2 storage can be calculated. Such quantity is important for oil companies to earn the carbon tax.

$$\text{Carbon}_{injection} = \text{Carbon}_{production} + \text{Carbon}_{storage} + \text{Carbon}_{emission}$$

If the produced CO_2 could be recycled,

$$\text{Carbon}_{production} = \text{Carbon}_{recycling}$$

The CO_2 mass balance model is shown in Fig. 1. The carbon quantification for the storage part is obtained from the research of Ivanova [4], whereas the potential leak paths during CO_2 storage are determined from the research of Simone [5].

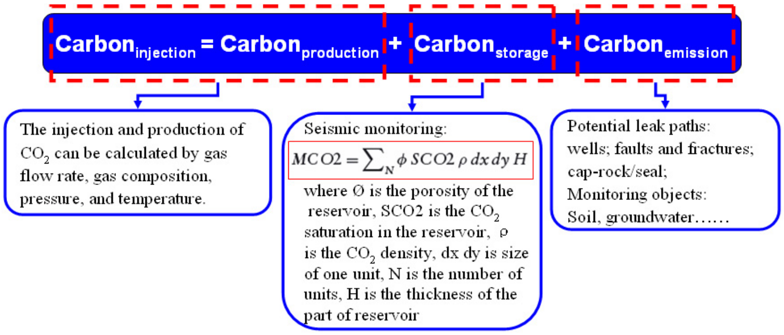

Fig. 1. CO_2 mass balance model during CO_2-EOR

3. CO_2 emission inventory during CO_2-EOR

CO_2-EOR technology is mature in the United States, and almost 90% of CO_2-EOR projects in the world are mainly distributed in Wyoming, the Permian Basin, and the Gulf Coast states [6]. In this section, each part of the CO_2 mass balance model was reviewed from the literature on CO_2-EOR projects, and CO_2 emission inventory was established. With consideration of the differences in injection scale, the functional unit was one tone injected CO_2.

(1) Carbon injection and production

In large-scale CO_2-EOR projects, CO_2 produced with oil is commonly separated, compressed, re-injected, and recycled numerous times. Therefore, the produced carbon part will be recycled to the injection wells. The CO_2 mass balance model can be simplified as follows: "injection carbon part is the sum of storage carbon and emission carbon." When the volumetric concentration of produced CO_2 is high, the recycled CO_2 will be moved to another part of the oilfield [7]. The re-injected CO_2 is more than 50% to 67% of the injected CO_2 [8].

(2) Carbon storage

Time-lapse 3D (4D seismic) is an extremely useful technology to quantify the storage mass of CO_2 in CO_2 storage and CO_2-EOR projects, including the projects of Weyburn, Sleipner, and Ketzin. Although some challenges exist from 4D seismic data process in terms of quantifying CO_2 storage [9], some projects have published the proportion of stored CO_2. For the Ketzin project, approximately 93% to 95% of injected CO_2 was stored [4]. For the Sleipner project, 85% of injected CO_2 was stored [10], whereas 10% of the free CO_2 was dissolved into the aqueous phase [11]. For the Weyburn project, only 62% to 70% of the net injected CO_2 was in the reservoir after one year of injection, and 30% to 36% immediately overlaid the reservoir. The produced CO_2 was then separated and compressed into an injection well for re-injection. After seven years of injection, approximately 92% to 94% of the net injected CO_2 was in the reservoir, and 5% to 6% overlaid the reservoir. The stored CO_2 was generally 92% to 95% of the injection [12].

(3) Carbon emission

A part of CO_2 could be transferred along the potential leak paths, such as wells, faults, fractures, cap-rock, or seals. For the Weyburn project, the maximum amount of CO_2 potentially residing above the regional sealing formation was less than 1% of injected CO_2 [2].

Near-surface environmental monitoring is necessary [13, 14]. Soil gas and underground water monitoring are the main objects used to identify the potential leak risks of carbon storage. In the Zero Emission Research and Technology Project, a laboratory-scale experiment on CO_2 injection and CO_2 emission from soil was conducted. When the injection rate of CO_2 was controlled at 0.3 t/d, the leak rate was estimated as 0.31 ± 0.05 t CO_2/d. The emission amount was more than 100% of injected CO_2 [15]. This experiment aimed to investigate the dynamics of CO_2 fluxes and concentrations during shallow subsurface CO_2 release. The experiment was not a real field experiment. For the CO_2-EOR project at the West Pearl Queen depleted oil formation, the CO_2 that leaked from soil was 0.014% of the total injected CO_2 [16]. For the Rangely CO_2-EOR project, the leaked soil CO_2 flux was 0.01% of the total injection [17]. For CO_2 dissolved into underground water, published quantification data were limited. The change in water quality was given considerable attention [18].

According to the results of the literature review, the proportion of each part of the CO_2 mass balance model indicated that 0.92 t to 0.95 t of CO_2 was stored in layers, whereas 0.0001 t to 0.00014 t CO_2 leaked from soil when 1 t CO_2 was injected. If the leaked part from soil was identified, some amount must exist along the leak paths. The remaining 0.05 t CO_2 may be the unmeasured amount, such as the part from the top of the storage layer to the subsurface, the amount dissolved into underground water, or the fixation by vegetation. Considering that this part comprises a large proportion of the total, subsequent research should focus on the carbon fate of the residual part.

4. Feasibility assessment of environmental monitoring technology

Underground monitoring technology is more meaningful than aboveground monitoring technology because of the atmospheric dilution of CO_2 [19]. The monitoring area can be vertically divided into three parts. The first part is the deepest layer. For a CO_2-EOR project, this part refers to the reservoir. The CO_2 plume can be simulated by seismic technology. For seismic technology, feasibility assessment depends on the signal strength and the 4D seismic noise level. The seismic signal will be weak at a deep reservoir depth. The second part is the near-surface part, i.e., that which is normally approximately 10 m underground. Gas flux, concentration, and isotope can be measured in this part. Near-surface monitoring technology has lower cost and easier operation than seismic monitoring technology. However, the challenges are the considerable interference sources, such as the degradation of organic carbon, and biological metabolism. The third part is the area from the top of the reservoir to the near-surface, i.e., the area along the leak paths. The literature on this part remains limited. However, this part may be much more important than the second part due to the proportion. Monitoring technology should be improved to focus on this part.

For each monitoring technology, baseline data should be carefully measured. The baseline data are not the only those measured before CO_2 injection. Process analysis is highly important during leakage risk identification.

5. Conclusions

This study reviewed the emission inventory of carbon injection, production, storage, and emission. Results indicated that only approximately 95% of injected CO_2 can be measured. The residual part may be that existing along leak paths. To develop a carbon mass balance model for CO_2-EOR projects, the emission part from soil and underground water, as well as the fixation by vegetation, should be carefully measured. The residual 5% that remains unmeasured should be proven, i.e., whether such amount is derived along leak paths or is emitted from near-surface sources. Findings could highlight the fate of carbon, provide some suggestions to guide the selection of environmental monitoring technology, and aid in establishing a common methodology to identify leak risks for carbon storage projects.

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References

[1] Zhang Y Y, Zhang Y, Zhang J. Environmental impacts of carbon capture, transmission, enhanced oil recovery, and sequestration: An overview. Environmental Forensics 2013; 14: 301-5.

[2] IEA GHG R&D programme interactive monitoring selection tool. (Sep 2013) http://ieaghg.org/ccs-resources/monitoring-selection-tool1

[3] Leach A, Mason C, van't Veld K. Co-optimization of enhanced oil recovery and carbon sequestration. Resource and Energy Economics 2011; 33: 893-912.

[4] Ivanova A, Kashubin A, Juhojuntti N, et al. Monitoring and volumetric estimation of injected CO_2 using 4D seismic, petrophysical data, core measurements and well logging: a case study at Ketzin, Germany. Geophysical Prospecting 2012; 60: 95-973.

[5] Simone A, Mackie E, Jenvey N. CO_2 geological storage field development-Application of baseline, monitoring and verification technology. Energy Procedia 2009; 1: 2219-2216.

[6] Leena K. 2012 worldwide EOR survey. Oil & Gas Journal 2012; 110: 57-69.

[7] Hill B, Hovorka S, Melzer S. Geologic carbon storage through enhanced oil recovery. Energy Procedia 2013; 37: 6808-6830.

[8] IPCC, 2005. IPCC special report on carbon dioxide capture and storage, in: Metz, B., Davidson, O., de Coninck, H., Loos, M., Meyer, L. (Eds.). Cambridge University Press for the Intergovernmental Panel on Climate Change, Cambridge.

[9] Lumley D. 4D Seismic monitoring of CO_2: Practical considerations. AAPG/SEG/SPE HEDBERG Conference "Geological carbon sequestration: Prediction and verification", Canada, 2009.

[10] Chadwick R, Arts R, Eiken O. 4D seismic quantification of a growing CO_2 plume at Sleipner, North Sea. In: Dore, A.G. and Vining, B. (eds), Petroleum Geology: North West Europe and Global Perspectives - Proceedings of the 6th Petroleum Geology Conference, Published by the Geological Society, London, 1385 – 1399.

[11] Chadwick A, Clochard V, Delepine N, et al. Quantitative analysis of time-lapse seismic monitoring at the Sleipner CO_2 storage operation. The Leading Edge 2010; 29: 170-177.

[12] White D. Toward quantitative CO_2 storage estimates from time-lapse 3D seismic travel times: An example from the IEA GHG Weyburn-Midale CO_2 monitoring and storage project. International Journal of Greenhouse Gas Control 2013; 16(S): S95-S102.

[13] Romanak K, Bennett P, Yang C, et al. Process-based approach to CO_2 leakage detection by vadose zone gas monitoring at geologic CO_2 storage sites. Geophysical Research Letters 2012; 39: 1-6.

[14] Sherk G, Romanak K, Dale J, et al. The Kerr investigation: Findings of the investigation into the impact of CO_2 on the Kerr property, final report. IPAC Res. Inc., Regina, Saskatchewan, Canada, 2011.

[15] Lewicki J, Hilley G, Dobeck L, et al. Dynamics of CO_2 fluxes and concentrations during a shallow subsurface CO_2 release. Environmental Earth Sciences 2010; 60: 285-297.

[16] Wells A, Diehl J, Bromhal G, et al. The use of tracers to assess leakage from the sequestration of CO_2 in a depleted oil reservoir, New Mexico, USA. Applied Geochemistry 2007; 22: 996-1016.

[17] Klusman R. A geochemical perspective and assessment of leakage potential for a mature carbon dioxide enhanced oil recovery project and as a prototype for carbon dioxide sequestration; Rangely field, Colorado. AAPG Bulletin 2003; 87: 1485-1507.

[18] Harvey O, Qafoku N, Cantrell K, et al. Geochemical implications of gas leakage associated with geologic CO_2 storage-A qualitative review. Environmental Science & Technology 2013; 47: 23-36.

[19] Klusman R. Comparison of surface and near-surface geochemical methods for detection of gas microseepage from carbon dioxide sequestration. International Journal of Greenhouse Gas Control 2011; 5: 1369-1392.