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A Novel Shallow Well Monitoring System for CCUS: With Application to Shengli Oilfield CO_2-EOR Project

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Abstract

The carbon dioxide (CO_2) flooding to improve the recovery ration of oil reservoir (EOR) is becoming one main way of EOR in the Shengli Oilfield, Shandong province, Northeast China. As one of the largest and oldest oilfields in China, the Shengli oilfield CCUS demonstration project is a true full-chain project from capture, pipeline transportation, utilization through storage. In particular, this CCUS project implements a wide spectrum of monitoring and assessments. A novel shallow well monitoring system is developed to detect the leakage of CO_2 at shallow formations. The core of this novel system is to adopt the U-tube sampling technology to accomplish collections of samples of water and gas in a convenient and cost-effective way. The shallow well is designated to a depth of 10 meters with a maximum five-block separation, i.e. it can obtain samples of water and/or gas at five different depths in maximum in a shallow well. The novel system has been tested to obtain geochemical samples of water and gas during a CO_2-EOR demonstration experiment conducted in the Shengli oilfield.

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Keywords: CO_2-EOR; Monitoring well; U-tube; Sampling technology; Baseline; Shengli oilfield; CCUS

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1. Introduction

The carbon dioxide (CO_2) flooding to improve the recovery ration of oil reservoir (EOR) has some merits such as extensive adaptability, low cost, high recoverability [1-3], and it is becoming one main way of EOR in the Shengli

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oilfield in future [4, 5]. The Shengli oilfield, located in Shandong province, Northeast China, is one of the largest and oldest oilfields in China (Fig. 1). The Shengli oilfield has high density oil in deep thin horizons. The field production peaked in 1991 at 33.55 million tons however the production has decreased to 27 million tons in 2012 with the overall water cut of 95% [4]. The decline in production and the increasing demand for fossil energy have motivated the Sinopec Group to seek a feasible CO_2-EOR solution for the sustainable development. In 2012, the Shengli oilfield starts a new challenging CCUS project under the National Key Technology Research and Development Program of the Ministry of Science and Technology of China [6]. Nearly all research institutes and universities of renown associated with China CCUS technologies are closely involved this ambitious demonstration project [6]. Through the demonstration, the Shengli oilfield in Qilu Petrochemical 500,000 tons/year of coal gas CCUS project and in Shengli Power Plant 1,000,000 tons/year of flue gas CCUS project are to be completed to capture 1,500,000 tons of carbon dioxide, which can satisfy the initial low permeability reservoir reserves of 70,000,000 tons scale flooding development needs [7].

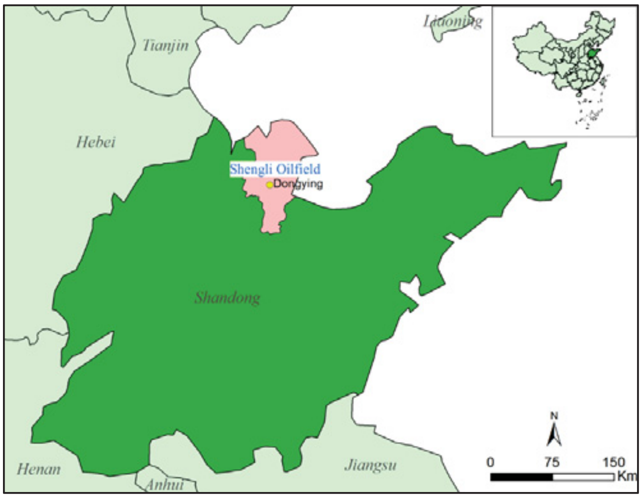

Fig. 1. Location map of Shengli Oilfield CO_2-EOR Project.

As China's second largest oilfield in carbon dioxide enhanced oil recovery and sequestration, the Shengli oilfield CCUS demonstration project is a true full-chain project from capture, pipeline transportation, utilization through storage [8]. In particular, this CCUS project implements a wide spectrum of monitoring and assessments including a three-scale baseline monitoring scheme other than the other two landmark CCS projects, i.e. Shenghua CCS demonstration project and Jilin oilfield CCS-EOR project [9-12]. As a consolidated part of the whole monitoring scheme of the Shengli oilfield CCUS demonstration project, a novel shallow well monitoring system is developed to detect the leakage of CO_2 at shallow formations [13]. The core of this novel system is to adopt the U-tube sampling technology to accomplish collections of samples of water and gas in a convenient and cost-effective way. The shallow well is designated to a depth of 10 meters with a maximum five-block separation, i.e. it can obtain samples of water and/or gas at five different depths in maximum in a shallow well. The novel system has been tested to obtain geochemical samples of water and gas from 10m depth during a CO_2-EOR demonstration experiment conducted in the Shengli oilfield in Dongying County, Shandong province, China. The sampling by this system is very different from the conceptual design and monitoring purpose of the traditional sampling of soil gas and underground fluid [13].

The paper mainly includes three sections. The first section introduces the novelty of the developed shallow well monitoring system. Then, the second section addresses the application of the novel system in the Shengli oilfield

CCUS project. Finally, the main results of the baseline monitoring from the first sampling by the system are depicted and concluded for the reference.

2. Monitoring System

2.1. Monitoring scheme

The CCUS projects must integrate appropriate monitoring programs and develop environmental impact assessments in order to gather and analyze required information and to communicate with stakeholders [14]. Monitoring is very important to verify the escape of CO_2 stored in geological formations [8, 15-17]. An integrated and cost-effective monitoring scheme is crucial for a commercialized CCUS project. Table 1 lists a suggestion scheme of (baseline) monitoring framework for China's CCUS project according to the general review of all related CCUS projects conducted around the world [10, 18]. It can be observed that the monitoring of soil gas and subsurface water is a very important part of the whole monitoring scheme.

2.2. Shallow well

Fig. 2 depicts the developed CO_2 monitoring system in a shallow well. The sampling is completed in three phases: Phase I, underground fluids in the aquifers flow across the orifice on the side wall of the borehole into the sampling segment of wellbore under differential pressure, and gradually achieve seepage balance; Phase II, underground fluids in the segment of wellbore flow into the U-tube through the cartridge filter and check valve, and fluid samples store in flow container of the U-tube. The two hoses connected to the upper ends of the U-tube are pressing end and sampling end, and all the hoses are connected to the wellhead; Phase III, after using nitrogen flushing clean, a portable nitrogen cylinder is connected to one end of the U-tube (pressing end), underground fluid samples stored in flow container of the U-tube are pushed to flow to the other end of the U-tube (sampling end). Then, the groundwater samples in the designated formation can be acquired at the wellhead.

Subsurface soil gas is extracted by using a piston-type gas sampler at the wellhead. It is worth noting that only soil gas above the water table is acquired, and the residual gas of unsaturated aquifers is excluded in this version of CO_2 monitoring system.

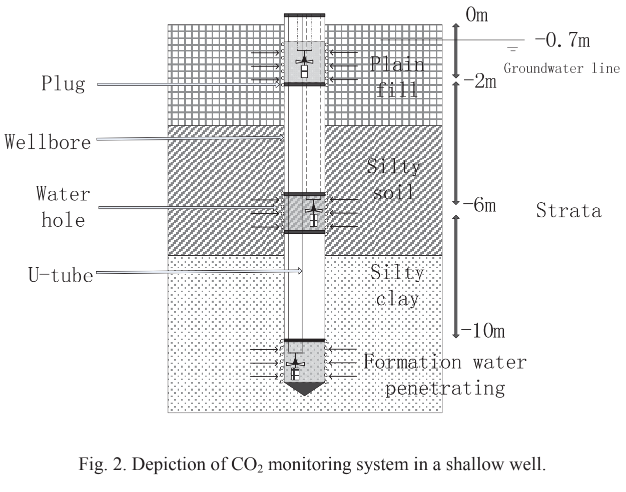

Fig. 2. Depiction of CO_2 monitoring system in a shallow well.

Table 1. Suggestion of (baseline) monitoring framework for China's CCUS project.

Main Type		**Object/Index**	**Instrument/Method**	**Frequency**
Atmosphere		Weather: air temperature, humidity, wind speed, atmospheric stability	Eddy covariance	Real time
		CO_2 flux	Eddy covariance	
		CO_2 concentration	Infrared diode laser	
		Stable isotope carbon-13 in air	Isotope analyzer	Monthly
		CO_2 emission sources survey	Model establishment of CO_2 sources from ecosystem, industry and agriculture	Once
Soil gas		Soil temperature, matric potential, water content	Underground sensors	Monthly
		Soil surface CO_2 flux	Soil respiration measurement system	
		CO_2 concentrations in soil gas under certain depth	Soil respiration measurement system	
		Other soil gas components: N_2, CH_4, O_2	Portable gas chromatograph	
		Ratio of stable isotope carbon-13 in soil gas	Isotope analyzer	
Vegetation ecology		Flora and fauna surveys	Quadrat survey	Once
		Vegetation Index	Airborne spectral imaging	Quarterly
Surface deformation		Vertical direction	Digital electronic level	Quarterly
		Horizontal direction	Precision total station	Quarterly
Water quality	Surface water	(1) Temperature, pH, TDS, TOC, TIC, Conductivity, Alkalinity (2) Major anions and cations (3) Gas component (4) Stable isotope carbon-13	(1) Glass electrode method, titration, combustion oxidation-non-dispersive infrared absorption method (2) Ion Chromatography (3) Gas chromatography (4) Mass spectrometry	Monthly
	Shallow groundwater			
	Groundwater in injected layers			
CO_2 subsurface transport		Changes in water level, flow velocity, flow direction	Rope, data logger	Monthly
		Fluid tracer	U-tube, applicable tracers: SF6, SF5, Kr, PFTs, PFCs, YCD4	Once
		Time lapse VSP		Once
		3D seismic exploration		Once
		Resistivity		Once
		Water-Rock-CO_2 interaction experiment		Once

2.3. U-tube

The monitoring well is approximately 10m deep within the precincts of the CO_2-EOR field. The PVC-U drainage pipe with 75mm diameter is used during the construction of the monitoring well. The monitoring well is equipped with the U-tubes [19, 20] at multiple formation depths, e.g., -2m, -6m, -10m, respectively, for independent sampling of groundwater and gas. The U-tube sampling system (Fig. 3) developed for the Shengli oilfield pilot tests utilizes a compressed gas to move the fluid to be sampled through a small diameter tube that goes down to the zone of interest and returns to the surface, forming a ‘‘U’’[19]. The schematic diagram of the U-tube sampler is depicted in Fig. 3.

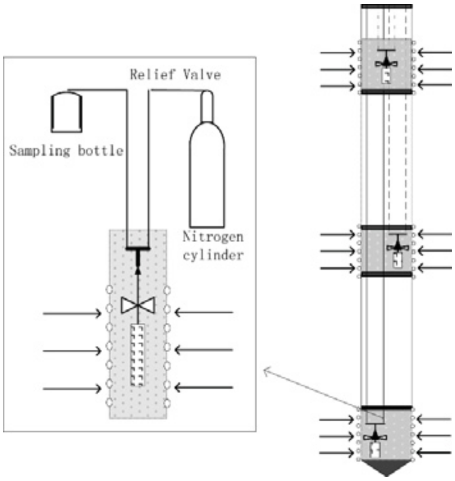

Fig. 3. The schematic diagram of the U-tube sampler.

3. Pilot Test

3.1. Test site

A novel sampler based on the U-tube technology was designed to extract formation water from strata during the operation of a CO_2-EOR project in Shengli oilfield (Fig. 1). This project are injected 1.5 Mtpa of CO_2 with the purity of 99.5% to meet the needs of recovery 70 million tons crude oil.

The project goals require a high-frequency of representative and uncontaminated samples, including soil gases and underground fluids, in order to monitor and identify potential CO_2 leakage from the subsurface [21], and also to assess induced HSE (Health, Safety and Environment) risks [22]. Hence, the borehole sampling data are periodically collected from three different depths of the formation through a 10m depth monitor well. The data could describe the geochemical changes in these fluid samples, thereby providing certain evidences of no CO_2 leakage during the implementation of CO_2-EOR in Shengli oilfield.

3.2. Results and discussion

The specially tailored CO_2 shallow well monitoring system works well in the oilfield. The results of on-site test samples are obtained using a scientific instrument Mutli 3420 (equipped with Sen Tix 950 pH electrode and TetraCon 925 conductivity electrode). The preliminary results of underground fluids of two different layers are given in Table 2, and they are compared the test results of nearby ditch water.

It should be noted that CO_2 leakage does not yet happen in this CO_2-EOR field, so the network of on-site shallow wells of the CO_2 monitoring system would give relatively stable sampling results. They can be regarded as the comparative baseline data of underground fluids properties of the test site, and they are also an evidence of no direct CO_2 leakage to shallow subsurface within the scope of the project area.

By periodic sampling of CO_2 monitoring system in shallow wells to identify actual CO_2 leakage within the scope of the project area is the next priority.

Table 2. The results of physical properties of one pilot test.

	Formation water at depth -2m	Formation water at depth -10m	Nearby ditch water
T (℃)	15.6	16.9	14
pH	8.049	8.046	7.578
TDS (g/L)	2.32	2.38	6.28
Salinity	1.2	1.2	3.4
Conductivity (ms/cm)	2.32	2.37	6.25
Resistivity (Ω*cm)	430	422	159.2

4. Conclusions

A novel shallow well sampler based on the U-tube technology was designed to extract formation water from strata during the operation of a CO_2-EOR pilot project in Shengli oilfield, Dongying, China. The first investigation of pilot tests from on-site samples are conducted, even though there is no leakage of CO_2 in this stage of CO_2-EOR project. However, further on-site tests and numerical simulation are helpful to verify the capacity of this novel monitoring system aimed at detecting and predicting the leakage of CO_2.

The strong demand of a shallow well monitoring system for actual projects has a good prospect and commercial value. The developed monitoring system can be widely used in different fields of environmental monitoring with different engineering purposes, especially for CO_2-EOR, CO_2-EGR, CO_2-ECBM, acid gas injection and shale gas recovery with monitoring of $CO_2/H_2S/CH_4$ leakage in shallow subsurface environment.

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