



Using stable carbon isotopes to track potential leakage of carbon dioxide: Example from an enhanced coal bed methane recovery site in West Virginia, USA



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ABSTRACT

Produced natural gas, shallow groundwater, and soil vadose gas samples were collected at the CONSOL Energy Inc. CO₂ Sequestration Pilot Test Site in Marshall County, WV to test the feasibility of using carbon isotope signatures to detect potential leakage of CO₂. CO₂ was injected into the Upper Freeport coal bed at a depth of ~396 m intermittently from September 2009 to December 2013. Water and gas samples were collected over a 12-month period (August 2013–August 2014). The injected CO₂ had $\delta^{13}\text{C}$ values ranging from -12.0‰ to -11.0‰ V-PDB. The average $\delta^{13}\text{C}_{\text{CO}_2}$ values of the soil vadose gas, the groundwater, and the produced CO₂ from overlying Pittsburgh coal bed were -25.0‰ , -16.6‰ and $+22.8\text{‰}$ V-PDB, respectively. These distinct carbon isotope signatures allow us to use $\delta^{13}\text{C}$ as a natural tracer to detect any potential leakage from the injected coal bed into the overlying monitored zones. In September 2013, the monitored downstream production well in Upper Freeport showed presence of injected CO₂ indicating injected CO₂ plume had migrated in the coal bed over the entire study area. However, the carbon isotope values observed in the overlying formations indicate no significant leakage of injected CO₂ from the underlying Upper Freeport coal bed.

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1. Introduction

Carbon capture and storage (CCS) has been a rapidly developing field of research in which new MVA (monitoring, verifying and accounting) techniques are being developed to quantify the amount of CO₂ stored within a geologic formation, as well as to monitor for potential leakage to the surface. Humans are responsible for releasing approximately 32 Gt of CO₂ into the atmosphere annually through processes such as the burning of fossil fuels (Atlas NACS, 2013). Potential reservoirs for the storage of this excess CO₂ through CCS include both conventional and unconventional reservoirs such as depleted oil and gas fields, deep saline aquifers and unmineable coal beds (White et al., 2005). This study is focused on an enhanced coal bed methane recovery site, in which CO₂ is injected into unmineable coal beds and adsorbs onto the surface of the coal while displacing coal bed methane and simultaneously

increasing the production of methane for industrial use (Mazzotti et al., 2009).

Extensive research at active CCS sites such as the Weyburn Oil Field in Saskatchewan, Canada has shown that monitoring geochemical parameters such as pH, alkalinity, major cations, and major anions and $\delta^{13}\text{C}_{\text{DIC}}$ of produced fluids at active injection sites allows for the tracking of a CO₂ plume within a system and can indicate storage through processes such as the dissolution of the injected CO₂ and subsequent ionic trapping of HCO₃[−] (Emberley et al., 2004; Emberley et al., 2005; Raistrick et al., 2006). Leakage of CO₂ from the CCS systems can occur through various natural and anthropogenically created pathways including, but not limited to, faults and cracked well casings or boreholes. Laboratory experiments, natural analogs, and artificial shallow leakage systems have been studied to understand the effects the leakage of CO₂ can have on systems such as shallow groundwater or soil vadose zones and to develop new monitoring techniques (Fessenden et al., 2010; Kharaka et al., 2010; Schulz et al., 2012). These artificial leakage sites have shown that after CO₂ is injected into a shallow groundwater aquifer there is a subsequent decrease in pH that can result in an increase in alkalinity and electrical conductivity (Schulz et al., 2012).

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Carbon isotope ratios have been successfully used in multiple MVA experiments for tracing the movement and ionic trapping of injected CO₂ (as bicarbonate) in the waters of carbonate and sandstone reservoirs at the Pembina and Weyburn oil fields, tracing the movement of injected CO₂ within a deep saline aquifer (Frio Formation), and have been used to trace leakage from artificial injection sites into overlying groundwater and the shallow soil vadose zone in Montana and Germany (Emberley et al., 2004, 2005; Fessenden et al., 2010; Johnson et al., 2011, 2009; Kharaka et al., 2006, 2010; Peter et al., 2012; Raistrick et al., 2006; Schulz et al., 2012).

The purpose of this study was to test the applicability of using carbon stable isotopes to monitor for potential leakage at the CONSOL Pilot carbon sequestration test site in Marshall County, West Virginia. Samples of the isotopic end-members (the injected CO₂, the overlying Pittsburgh coal bed, shallow groundwater and soil vadose gas) were collected at the site during and after CO₂ injection. The isotopic variations observed in the different end-members were analyzed and interpreted keeping in perspective the fractionation processes that cause the natural variations in these systems. Monitoring for abnormal isotopic shifts in the $\delta^{13}\text{C}$ of the samples could indicate significant leakage from the coal bed in which CO₂ was injected.

1.1. Study area

The CONSOL Energy Carbon Sequestration Pilot Test Site is located near Georgetown, WV on the eastern edge of the northern WV panhandle in Marshall County bordering Greene County, PA (Fig. 1).

The study site was set up to determine if there is leakage of CO₂ to the surface during the injection period in an ECBM recovery system. Baseline geochemical monitoring began in 2008. Injection began in 2009 and continued with some disruptions until 2013. Baseline isotope samples were not available for this study as the authors became involved with the Pilot Test site project in Fall of 2012. However, due to breaks in CO₂ injection and weather conditions continuous sampling for this study could not begin till August of 2013. The isotope monitoring occurred during the period of ongoing injection and then post-injection monitoring continued through August 2014 (Fig. 2).

In September of 2013, a high CO₂ mol% was recorded at a downstream Upper Freeport well and injection was discontinued for an investigation of the cause of the high CO₂ mol%. Injection resumed in October 2013 until early November 2013 due to a pump failure. The injection system was offline until the end of December 2013. In January 2014, the scheduled post-injection monitoring period began and will continue through December of 2015 (Winschel et al., 2010).

The site is approximately 1 km² in size and is bounded on all sides by underground horizontal methane production lines. There were five (5) CBM production wells, three (3) groundwater wells, and seven (7) soil vadose gas sampling locations for carbon isotopes during this study (Hega et al., 2011; Locke et al., 2011; Rauch et al., 2012; Winschel et al., 2010).

The production wells for this site were set up in a modified five spot pattern. There were three different locations of production wells drilled for this project on this site. MH-3 & MH-5 are at the northern most drill location. MH-11 & MH-12 are located at the southernmost drill location (Fig. 1). MH-18 & MH-20 were originally production wells that were modified into injection wells and are located at the center of the site. The horizontal laterals of the MH-18 well extend toward the north and west directions. The horizontal laterals of MH-20 extend toward south and east direction (Rauch et al., 2012; Winschel et al., 2010). The northern production wells, MH-5 & MH-3, produce gas from the Upper Freeport and the Pittsburgh coal beds respectively.

At the southern edge of the site area there are three production wells. MH-11 & MH-12 are located together with MC5-PG nearby. MH-12 and MC5-PG both produce from the Pittsburgh coal bed, while MH-11 produces from the Upper Freeport. The groundwater and soil vadose gas sampling locations are all located along the access road that runs through the middle of the test site. The groundwater wells, W-1, W-2, and W-3, are shown on Fig. 1 as blue circles. As shown in the cross section (Fig. 3), the groundwater samples are collected from the Washington formation within the Dunkard group located at a depth of approximately 30 m below the surface.

The soil vadose wells W-1A, W-2A, W-2D and W-3A are located close to their counterpart groundwater wells; W-5 is the southern most of the soil vadose sampling wells; and W-4 and W-7 are the furthest along the access road, west of the injection wells. All of the soil sampling wells collect gas from approximately 1–2 m below the surface (Winschel et al., 2010).

The geology in the area of the Marshall County test site is a relatively simple sedimentary sequence with clastic sedimentary rocks, limestones and coals (Fig. 1). This project focuses on two coal beds, the younger Pittsburgh coal bed and the older Upper Freeport coal bed. The Pittsburgh coal is the oldest formation within the Pennsylvanian age Monongahela group. At the Marshall county site it is at a depth of approximately 213 m below the valley bottom land surface. The Upper Freeport coal is the youngest formation within the Pennsylvanian age Allegheny group. This coal bed depth is reported to be approximately 396 m below the valley bottom land surface at the test site. CO₂ was injected into the Upper Freeport coal bed (Locke et al., 2011; Ruppert and Rice, 2001; Ruppert et al., 2002; Winschel et al., 2010).

The dip of the rocks in the region is ~2 to 3° to the S/E. The Washington Anticline is to the northwest of the site area and there are no major faults reported running through the injection study area (Wilson et al., 2009).

2. Methods

Sampling for this project took place over a 12-month period from August 2013 to August 2014. The three (3) groundwater and seven (7) soil gas samples were collected monthly when possible. Produced gas from the Pittsburgh coal bed was collected quarterly. Injected CO₂ was analyzed three times during the injection period to prove consistency. In May 2014, vegetation samples were collected for $\delta^{13}\text{C}$ analysis. During a sampling trip all of the samples listed above were collected on the same day, before noon. One set of samples (soil vadose, groundwater and produced gas—Aug 2013) were collected during an extended period of injection. The other remaining samples were collected during times when the system was down or during the post injection-monitoring phase of the project (Fig. 2). Field parameters such as pH and temperature and other geochemical parameters such as cations and anions were collected by Dr. Rauch's research group at WVU.

During the fieldwork in May 2014 samples of plant matter, leaves, and grasses were collected within a 5-ft radius around the soil vadose wells. There were a total of 7 vegetation samples: W1A, W2A, W2D, W3A, W4, W5, and W7, all named to the corresponding nearby soil vadose wells.

Soil vadose gas samples were collected from a vadose well casing port on an in-situ device constructed of PVC pipe that was connected to a piece of rubber tubing that reached a screened interval from approximately 1–1.5 m. Gas bench sampling vials (15 mL) filled with He were attached to a needle on a sampling port via a rubber septa and allowed to equilibrate for 30 min with diffused soil vadose gas.

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