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Early Operational Experience at a One-million Tonne CCS Demonstration Project, Decatur, Illinois, USA

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Abstract

After four years of site-specific work, carbon dioxide (CO_2) injection began at the Illinois Basin – Decatur Project (IBDP) in Decatur, Illinois USA on 17 November 2011. The IBDP is a demonstration project in one of the Regional Carbon Sequestration Partnerships (Phase III) funded by the US Department of Energy. Work at IBDP was preceded by two years of regional basin studies and identification of a CO_2 source located optimally with respect to a major saline reservoir, the Mount Simon Sandstone, believed capable of safely and effectively containing gigatonne-scale quantities of sequestered CO_2 in the Illinois Basin of Illinois, southwestern Indiana, and western Kentucky, USA. Early operational experience has been a function of reservoir properties and the infrastructure put in place to demonstrate carbon capture and storage (CCS). Development of the site included construction of a compression/ dehydration facility and a 1.9 km pipeline, drilling of three wells, and development of a real-time data collection system to monitor operational parameters. As of 11 October 2012, 288,000 tonnes of dense-phase (supercritical) CO_2 have been injected, and injection continues at a rate of 1,000 tonnes per day.

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1. Introduction

The IBDP is the saline reservoir project of the Midwest Geological Sequestration Consortium (MGSC), one of the Phase III projects of the US Department of Energy's Regional Carbon Sequestration Partnership (RCSP) program. The IBDP is the first demonstration-scale (1 million tonnes permitted) RSCP project supplied from an industrial source in the United States (Fig. 1).

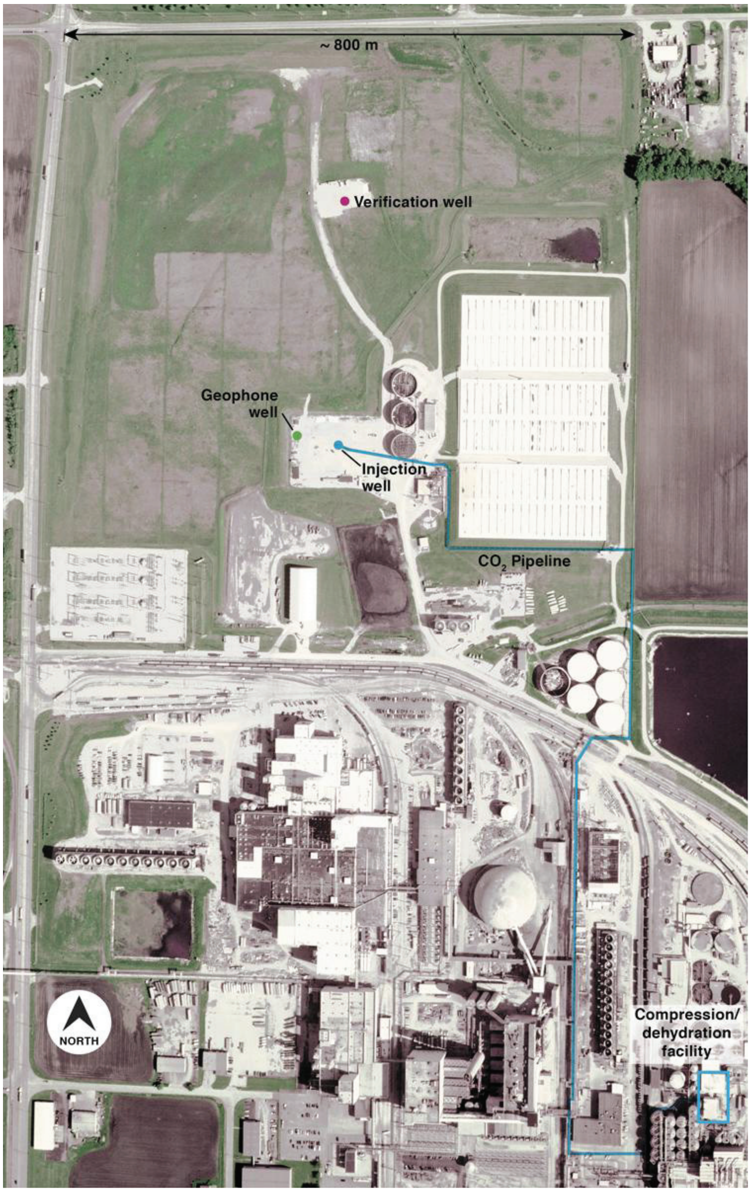

Fig. 1. Aerial view of the IBDP site showing project components.

The major MGSC IBDP collaborators are the Illinois State Geological Survey, Schlumberger Carbon Services, Trimeric Corporation, and the Archer Daniels Midland Company (ADM) [1]. ADM is a global agricultural products processing company and supplies the 99+ percent pure CO_2 as a byproduct of the fermentation of corn to produce ethanol as a motor fuel component. ADM also owns the injection site, operates the compression facility, and holds the Underground Injection Control (UIC) permit required under US environmental regulations.

The IBDP is an integrated industrial CCS system from the source to the reservoir. It includes a 2,190 m deep injection well, a 2,201 m deep observation well, and a 1,050 m deep geophysical well containing a string of 31 multicomponent geophones cemented in place. All three wells and an extensive network of environmental monitoring sites are contained within an 800 x 800 site; additional monitoring takes place surrounding the site. The observation well is perforated at 11 intervals, nine in the Mount Simon, and two above the primary shale seal and is fitted with the Westbay* multilevel groundwater characterization and monitoring system to allow continuous pressure monitoring and periodic fluid sampling. The geophysical well is located on the injection well pad and the observation well is located 300 m north-northeast of the injector. The injection well is fitted with three multicomponent microseismic sensors that were deployed using tubing and hydraulically released to acoustically couple to the formation through the casing. Dense phase CO_2 is delivered to the injection well via a 1.9 km, 6-inch diameter pipeline supplied by two four-stage reciprocating compressors with an integrated glycol dehydration system with output pressure up to 97 bars.

2. Reservoir and Seal Site Characterization

Pre-injection characterization of the reservoir-seal system at the IBDP site indicated favorable capacity, injectivity, and containment that are now being confirmed [2]. The original assessments took place as part of regional studies within the Illinois Basin carried out from 2003-2005. The system consists of 500 m of Mount Simon Sandstone overlain by 151 m of Eau Claire Shale acting as the seal. The Mount Simon was deposited in the cratonic Illinois Basin as a stack of sand-rich braided fluvial deposits transitioning upward to shelf and tidal bar sandstones prior to the Eau Claire marine transgression. The lower Eau Claire consists of 60 m of black marine shale and impermeable, silty mudstone while the upper part consists of low-permeability siltstones and carbonates. Injection is taking place through 16.7 m of perforations over a depth range of 2,117 to 2,136 m at the base of the Mount Simon with average interval porosity of 20 percent and permeability of 185 md. Over 110 m of whole core drilled from the lower Mount Simon and analysis of well logs shows generally excellent reservoir quality over the lower 200 m of the reservoir, but thin lower Mount Simon strata with permeability in the range <1 md will act as baffles to vertical carbon dioxide migration, as indicated by reservoir modeling and demonstrated by pressure data in the observation well. These baffles contain authigenic quartz which occludes pore space.

Initial site-specific work consisted of orthogonal 2D seismic lines run in 2007 along roads adjacent to the west and north boundaries of the site. These lines showed no seismically resolvable faulting that could compromise the site integrity and serve as leakage pathways. The next step was to drill the injection well (February-May 2009) to obtain well logs, whole core and drilled sidewall cores, and provide time-to-depth conversion for the 2D seismic and subsequent 3D seismic (run in winter 2009-10). Core and logs confirmed the regional interpretation of the reservoir-seal system, and the 3D seismic survey did not resolve any faulting that would have compromised the site.

3. Permitting

The IBDP is operated on a site provided by ADM who also operates the injection facility on a 24/7 basis. ADM is the holder of the Underground Injection Control (UIC) permit required for underground injection of CO_2 in the United States. The project currently holds a Class I Nonhazardous permit issued by the Illinois Environmental Protection Agency (IEPA). At the time the initial permit application was made (January 2008) the Class VI rules specific to CO_2 storage now in place under the authority of the US EPA were just in the early stages of development and not yet in draft form. By the time the injection well was drilled in 2009, however, Class VI rules existed in draft form and were used to guide the construction and completion of the injection well. In accordance with Class VI requirements, all three casing strings were cemented back to surface, the bottom 600 m of the long string casing consists of 13-chrome CO_2 resistant steel, and the cement surrounding the long string from the bottom of the well up into the intermediate casing consists of CO_2-resistant cement.

4. Initial Operations and Commissioning

The authorization to inject was received from the Illinois EPA on 2 November 2011, and first CO_2 was injected into the well on 4 November 2011. An initial period of equipment evalauation, such as tuning of vents at the compression facility and maintaining pressure on the tubing-casing annulus, was required, and continuous injection was initiated on 17 November 2011. To maintain compliance with the permit, commissioning of the system involved such adjustments as flow rate (capped at 1,050 tonnes/day by permit), temperature of carbon dioxide at the wellhead, and pressure in the tubing-casing annulus, as well as accommodating system venting requirements, such as when one of the two compressors went offline. Several weeks of operating under various conditions of rate and ambient temperature were required to refine the system. The reservoir readily accepted the injected CO_2 from the first day of injection and no abnormal back pressure or other adverse events occurred during startup. Full injection rate of 1,000 tonnes/day was achieved with only 24.1 bar bottomhole pressure increase over static reservoir pressure. A pressure response was seen at the observation well within hours after less than 200 tonnes was injected. After 50,000 tonnes had been injected, reservoir pressure increases in the observation well up to 11 bars were observed to begin leveling off. This response suggests very good lateral reservoir continuity at the perforation level, as might be expected for a reservoir deposited as a sand-rich braided fluvial system. The first post-injection 3D vertical seismic profile was obtained in March 2012 to define early plume geometry, and, at the same time, all three wells were logged with the RST* reservoir saturation tool to determine near-wellbore CO_2 saturation.

5. Early Monitoring During Injection

The depositional system of the lower Mount Simon Sandstone was primarily a terrestrial braided river and alluvial fan system with some eolian-playa and interdune environments. The Mount Simon is characterized by intervals of coarse grained, cross-bedded sandstone to pebble conglomerates (braided river deposition) and other intervals dominated by medium to fine-grained, cross-bedded, planar and ripple laminated, and mottled sandstones with occasional coarse to fine pebble lags (braided river and eolian deposition). In terrestrial depositional systems, such as those found in the lower Mt. Simon, there occur interconnected sandstone bodies with variable depositional extent, but which appear to form larger flow units through sand-on-sand contacts. In the Mt. Simon, there occur numerous lower permeability stratigraphic intervals, some due to diagenesis, that act as baffles to slow the vertical migration of CO_2.

5.1 Verification Well Sees CO_2 in March 2012

The Mount Simon reservoir has been performing as expected and the CO_2 is being readily injected at a wellhead injection pressure of about 93 bar (1,350 psi) and a temperature of 35°C (95°F). CO_2 reached the verification well in March 2012, which was sooner than expected. Logging showed about a 2 m (6 ft) thick interval with CO_2 in a zone equivalent to the upper of the two perforated intervals open in the injection well. The lower zone in the verification well showed CO_2 by July 2012. These occurrences in the verification well, 300 m (1,000 ft) from the injection well show that the CO_2 is readily spreading and that the plume is relatively thin, although buoyant height growth is evident around the injection well as shown by cased-hole logging.

A representative reservoir model was built using all available data and calibrated with the field data acquired through April 2012. In order to calibrate the reservoir model, the simulator was fed with the observed injection rate and asked to predict injection bottomhole pressures and the pressures at five different zones at the verification well. The simulated pressures were then compared to the observed pressures. Reservoir permeability and skin at different perforations were fine-tuned to calibrate injection bottomhole pressure and flow partitioning that was measured with production logging. The match in injection bottomhole pressure is shown in Figure 2. In this figure, green data points and the black solid line represent the measured and simulated bottomhole pressures, respectively.

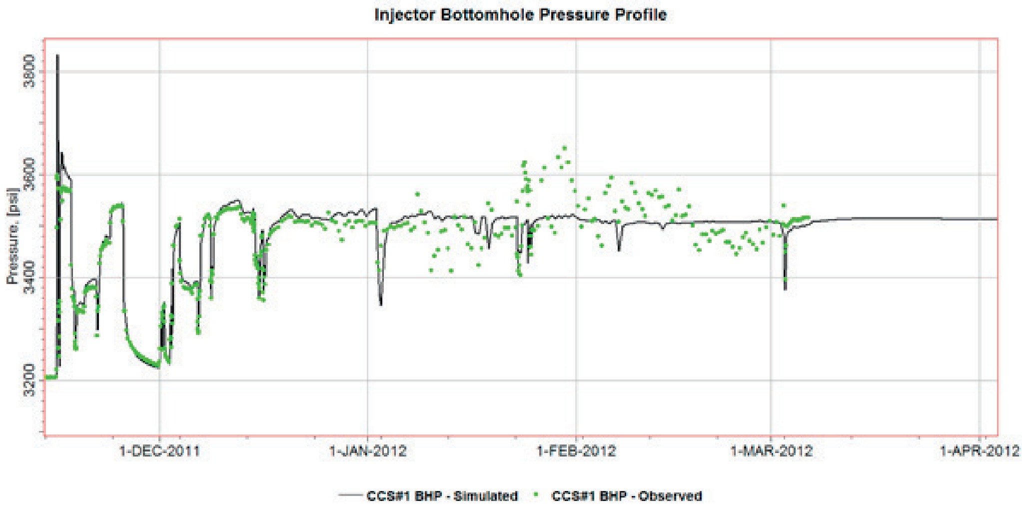

Fig. 2. Comparison of early reservoir pressures and simulated bottomhole pressure.

Once the injection bottomhole pressure was calibrated, simulated pressures in five different zones at the verification well were fine-tuned adjusting k_v/k_h ratio. RST well logs helped us estimate the depth, saturation, and thickness of the CO_2 around the injector well and arrival time of CO_2 to verification well. The first RST run and fluid sampling in March 2012 proved low saturations of CO_2 in the observation well (VW#1) right under Zone 3. This information helped us calibrate the end points of relative permeability curves which dominate the CO_2 and brine flow in the reservoir. A good match on CO_2

arrival time was obtained and demonstrated (Figure 3). In this figure, a plan view of the predicted CO_2 plume footprint is superimposed on a satellite image to demonstrate the extent of the plume at the time of breakthrough at VW#1.

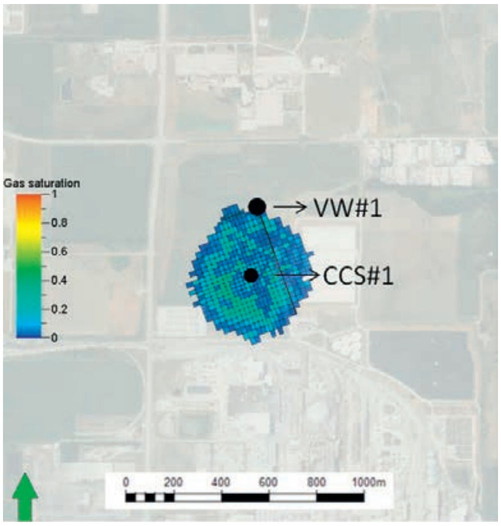

Fig. 3. Simulated reservoir CO_2 distribution in March 2012.

5.2 3D Vertical Seismic Profile (VSP)Monitoring

Time-lapse 3D VSPs were selected as a primary seismic monitoring tool early in the project planning stages as the reservoir simulations predicted that the CO_2 would not migrate beyond the imaging aperture of a 3D VSP over the three-year injection period [3]. The time-lapse 3D VSPs are being acquired using the 31-level multicomponent geophone array. Data repeatability is critical to the success of any time-lapse seismic survey, and the use of a permanent geophone array eliminates the receiver related repeatability errors.

Two baseline surveys and one monitor 3D VSP survey have been acquired at the site through September 2012. The time-lapse analysis has focused on the Baseline 2 and Monitor 1 surveys as these 2 surveys have the most similar acquisition parameters and conditions. Monitor 1 was acquired after ~70,000 tonnes of CO_2 had been injected into the lower Mt. Simon Sandstone. This is a relatively small amount of CO_2 to detect seismically, but Monitor 1 was timed to coincide with the first round of RST logging and fluid sampling from Verification Well #1. In addition, if the CO_2 has been confined to a thin layer in the lower Mt. Simon formation as other monitoring data suggests, it will also be difficult to detect seismically.

The direct difference display between Baseline 2 and Monitor 1 does not seem to show any definitive differences that have been caused by CO_2 injection. However, the Normalized Root Mean Square (NRMS) repeatability metric shows a number of interesting features at the injection interval. The NRMS metric indicates that Baseline 2 and Monitor 1 are highly repeatable in the zones above the lower Mt. Simon Sandstone with NRMS values ranging from 9 to 20 %. Over the injection interval, the NRMS values are much higher and range from 35 to 65%. Some of these high NRMS values are certainly related to low fold at the depth of injection, but others correspond to areas with good fold coverage and may be suggestive of CO_2 movement within the Mt. Simon.

6. Conclusions

The Illinois Basin – Decatur Project of the MGSC has successfully completed nearly one year of CO_2 injection at a nominal rate of 1,000 tonnes/day with cumulative injection of over 288,000 tonnes as of 11 October 2012, and expectations of injectivity and capacity of the Mount Simon Sandstone have been met. Cased-hole logging has shown that CO_2 volumes injected to date remain in the lower Mount Simon, and reservoir simulation shows the sealing capacity of the Mount Simon-Eau Claire Shale interface will not be tested even 100 years after injection of 1 million tonnes ceases. Early breakthrough of CO_2 at the verification well suggests that the sand-rich Mount Simon reservoir has better than expected lateral flow continuity toward the north, possibly related to the depositional dip direction of the braided-fluvial systems generally from the north into the Illinois Basin. The compression/dehydration, pipeline, and injection well system has operated as planned with ADM carrying out 24/7 injection operations fully integrated with their ethanol production facility.

*Mark of Schlumberger

7. Acknowledgements

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