Characterization and Time-Lapse Monitoring Utilizing Pulsed-Neutron Well Logging At An Incidental CO_2 Storage Demonstration

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Abstract

The Plains CO_2 Reduction (PCOR) Partnership is working with Denbury Resources Inc. (Denbury) and Schlumberger Carbon Services to carry out a time-lapse pulsed-neutron well logging (PNL) campaign as part of the site characterization and monitoring activities at the Bell Creek oil field. This is being carried out to study incidental carbon dioxide (CO_2) storage associated with large-scale injection of CO_2 for enhanced oil recovery (EOR) and to develop the tools, techniques, and approaches for long-term monitoring of geologic CO_2 incidental storage (Gorecki and others, 2012).

The planned injection of approximately 50 million cubic feet per day (MMscf/day) of CO_2 began in May of 2013 as part of Denbury's CO_2 EOR project at the Bell Creek oil field. Discovered in 1967, the Bell Creek oil field in southeastern Montana has produced over 130 million barrels (MMbbl) of oil from the Lower Cretaceous Muddy Formation sandstone, which is approximately 4500 feet in depth. Original oil in place (OOIP) is estimated to be over 350 MMbbl. Through primary and secondary recovery, about 38% of the OOIP has been produced. It is estimated that the planned CO_2 EOR operations being carried out by Denbury will produce approximately 40–50 MMbbl of additional oil from the field, while injecting large volumes of CO_2 in the same deep subsurface formation that has stored the oil.

The PCOR Partnership is focused on site characterization, modeling and simulation, risk assessment, and monitoring the movement of CO_2 in the reservoir and the CO_2 that is incidentally stored as a part of normal EOR operations. This is accomplished through an adaptive management

strategy for incidental CO_2 storage monitoring that is designed to select the most fit-for-purpose, cost-effective techniques to characterize the site and monitor the incidental storage and movement of CO_2 in the injection horizon.

Available techniques for monitoring saturation changes throughout the stratigraphic column over a large geographic area are often limited and/or cost-prohibitive because of the lack of available access to the subsurface. Simultaneous injection and production associated with large-scale EOR operations further limit applicable techniques. PNL allows the use of existing wellbores to monitor saturation changes in the subsurface with limited impact to EOR operations. Time-lapse CO_2 saturation data are also anticipated to provide valuable input for history-matching predictive simulations and provide a supplemental data set to enhance time-lapse seismic interpretations. As part of a baseline monitoring and characterization effort, sigma and carbon/oxygen (C/O) logs were collected as part of a 33-well PNL program conducted immediately prior to CO_2 injection.

Baseline sigma logs were collected to evaluate porosity and fluid saturations and time-lapse fluid and gas saturation changes through the Muddy Formation and overlying formations during EOR operations. Understanding near-wellbore fluid/gas saturations will provide a mechanism to identify and quantify (if present) vertical migration and/or accumulation of CO_2 throughout the injection area. However, the low-salinity environment (<5000-ppm total dissolved solids) present in the Muddy Formation and overlying strata make quantifying water and oil saturations difficult utilizing sigma measurements because of the low contrast in the thermal neutron capture cross section (sigma) of freshwater (~22.2 cu) and oil (~20 cu) (Schlumberger, 2009). To better understand the reservoir interval, C/O ratio logging was conducted to provide accurate water/oil/gas saturations and time-lapse changes in these saturations. Because of the low gas-to-oil ratio (GOR), any changes in gas saturations can be primarily attributed to the presence of CO_2.

The baseline sigma and C/O log campaign proved valuable for characterizing system porosity, lithology, and saturations in a historic reservoir with limited data outside the injection horizon. Sigma logging provided a means of collecting through-casing porosity and gamma ray data of strata overlying the Muddy Formation. C/O ratio logging provided additional lithology information that was used to better characterize the injection target and allowed for qualitative evaluation of residual oil saturations within various discrete intervals of the Muddy Formation. Prior to PNL, geologic property data were limited throughout the majority of the Bell Creek oil field, particularly for strata overlying the Muddy Formation, which serve as seals and potential zones to monitor for CO_2 migration. The geologic properties of these strata are important for guiding specific monitoring efforts, enhancing interpretation of seismic data, ensuring site security, evaluating CO_2 flood/incidental storage performance, and understanding the ultimate storage capacity of the reservoir.

The first time-lapse PNL surveys are ongoing, with a planned 4-D vertical seismic profile acquisition once CO_2 breakthrough has occurred from reservoir injector to reservoir producer and production response has normalized. It is anticipated that PNL data, in conjunction with other monitoring techniques, will provide conclusive data sets related to site security and wellbore integrity and will provide a mechanism to evaluate flood/storage efficiency under various operational parameters. Additionally, the data sets generated will allow for enhanced interpretation of seismic and other monitoring data sets and provide a case study evaluating sigma and C/O logging for CO_2 saturation monitoring in low-salinity environments. PNL at Bell Creek will help establish the relationship between the CO_2 EOR process and long-term incidental storage of CO_2 and help establish monitoring, verification, and accounting methods that can safely and effectively monitor commercial-scale simultaneous CO_2 EOR and incidental CO_2 storage operations in a cost-effective manner that is compatible and mutually beneficial to both Denbury's EOR operation and the PCOR Partnership's monitoring study.

References

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