CHARACTERIZATION AND TIME-LAPSE MONITORING OF A COMBINED CO_2 EOR AND CO_2 STORAGE PROJECT AT THE BELL CREEK OIL FIELD UTILIZING PULSED NEUTRON WELL LOGGING

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The Plains CO_2 Reduction Partnership is working with Denbury Resources Inc. (Denbury) and Schlumberger to carry out a time-lapse pulsed neutron well logging (PNL) campaign as part of an iterative approach to site characterization, modeling and predictive simulation, monitoring and risk assessment at the Bell Creek oil field to evaluate the efficiency of a large-scale injection of carbon dioxide (CO_2) for simultaneous CO_2 enhanced oil recovery (EOR) and long-term CO_2 storage (Gorecki and others, 2012).

Initial injection of approximately 50 MMscf/day of CO_2 is anticipated to begin by mid-2013 as part of the combined CO_2 EOR and CO_2 storage project at the Denbury-operated Bell Creek oil field, which covers approximately 22,000 acres and contains over 450 wellbores. 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' 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 30 MMbbl of additional oil from the field, while simultaneously storing large volumes of CO_2 in the same deep subsurface formation that has stored the oil.

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 limits applicable techniques. PNL allows the use of existing wellbores to monitor saturation changes in the subsurface with limited impact to EOR operations.

The PNL program is anticipated to be a cost-effective means of providing key characterization data throughout the stratigraphic column and a means of monitoring site security and EOR flood/CO_2 storage efficiency. 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 30-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.

C/O ratio logging was conducted over the reservoir interval to provide accurate water/oil/gas saturations and time-lapse changes in these saturations. The low-salinity environment (<5000 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 evaluate sweep/storage efficiency under various operational parameters, C/O logging will be utilized to understand water/oil/gas saturation changes within the Muddy Formation interval. 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, assuring site security, evaluating CO_2 flood/storage performance, and understanding the ultimate storage capacity of the reservoir.

The first time-lapse PNL surveys are expected to occur in late 2013 in conjunction with a planned 4-D seismic acquisition once CO_2 breakthrough has occurred 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 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 CO_2 storage operations in a cost-effective manner that is compatible and mutually beneficial to both project components.

References

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