A Database and Probabilistic Assessment Methodology for Carbon Dioxide Enhanced Oil Recovery and Associated Carbon Dioxide Retention in the United States

Peter D. Warwick¹, Mahendra K. Verma², Emil D. Attanasi¹, Ricardo A. Olea¹, Madalyn S. Blondes¹, Philip A. Freeman¹, Sean T. Brennan¹, Matthew D. Merrill¹, Hossein Jahediesfanjani³, Jacqueline Roueche³, and Celeste D. Lohr¹

¹ U.S. Geological Survey, Reston, VA, USA
² U.S. Geological Survey, Riverside, CA, USA
³ Lynxnet, LLC, Herndon, VA, USA

Abstract

The U.S. Energy Independence and Security Act of 2007 authorized the U.S. Geological Survey (USGS) to conduct a national assessment of the potential volume of hydrocarbons recoverable by injection of carbon dioxide (CO₂) in known oil reservoirs with historical production. The implementation of CO₂ enhanced oil recovery (CO₂-EOR) techniques can increase the U.S. recoverable oil resource base. Use of anthropogenic CO₂ in the CO₂-EOR process can reduce the amount of CO₂ released to the atmosphere by storing a percentage of the injected CO₂ in reservoir pore space vacated by produced oil or by CO₂ dissolution in oil and water in the reservoir.

A Comprehensive Resource Database (CRD) was prepared to support the planned USGS assessment. The CRD contains proprietary data on location, geologic, petrophysical, and reservoir parameters, production, and well counts for major oil and gas reservoirs in onshore areas and State waters of the conterminous United States and Alaska. The CRD contains field and reservoir data from the Nehring Associates Inc. (2012, Significant Oil and Gas Fields of the United States database) and production and drilling data from IHS, Inc. (2012, Petroleum Information Data Model of relational U.S. well data). Algorithms based on play, province, region, or national averages were used to (1) estimate missing reservoir values in the Nehring Associates, Inc. (2012) database and (2) generate values of additional variables, such as minimum miscibility pressure and fracture pressure, used to characterize reservoirs suitable for miscible or immiscible CO₂ flooding for EOR. The reservoirs in the CRD are organized by the geologic plays and provinces identified in the USGS 1995 National Oil and Gas Assessment (U.S. Geological Survey Digital Data Series DDS-35, http://pubs.usgs.gov/dds/dds-035/). The CRD identifies more than 7,000 reservoirs in the United States that are suitable for the CO₂-EOR process using screening criteria based on production-based gas-oil ratio, API gravity, reservoir volume, oil viscosity, minimum miscibility pressure, and reservoir fracture pressure.

The USGS developed a new methodology for the national assessment of technically recoverable oil resources that may be produced using current CO₂-EOR technology. The methodology relies on the CRD reservoir database and its estimates of original oil-in-place (OOIP) volumes for each reservoir. For each play that has suitable reservoirs for CO₂-EOR, USGS geologists evaluate probability distributions associated with estimates of average porosity and original oil saturation for the largest
representative reservoirs within the play. Monte Carlo simulation is used to produce a numerical probability distribution for the OOIP, with the mean defined as the database OOIP. The resulting dimensionless distribution is applied to the database point estimates of other EOR reservoir candidates in the play. A reservoir simulator (CO₂ Prophet, developed for the U.S. Department of Energy by Texaco, Inc.) is used to determine the incremental recovery factors for oil during the CO₂-EOR process, on an individual reservoir basis. The simulator is also used to estimate the volume of CO₂ remaining in the reservoir after the CO₂-EOR process is complete. Empirical decline curve analysis and comparison to data from published papers and reports on CO₂-EOR projects are utilized to substantiate the simulation results. Numerical distributions of recovery factors are prepared based on the EOR method (miscible or immiscible) and reservoir lithology (clastic or carbonate). The distribution of incremental oil is computed by multiplying the appropriate probability distribution of recovery factors by the individual reservoir distribution of OOIP. Assessment results will be aggregated at the play, basin, region, and national scales. This assessment methodology has been tested on the Permian Basin Horseshoe Atoll, Upper Pennsylvanian–Wolfcampian Play (Texas), comprised of 33 reservoirs that are amenable to the CO₂-EOR process. The play was selected as a test case because CO₂-EOR production data and published reports are available for several reservoirs. Preliminary estimates are comparable to those reported in the literature and obtained by reservoir decline curve analysis.