Summary of the Analyses for Recovery Factors

By Mahendra K. Verma

Chapter E of
Three Approaches for
Estimating Recovery Factors in
Carbon Dioxide Enhanced Oil Recovery
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Overview

In order to determine the hydrocarbon potential of oil reservoirs within the U.S. sedimentary basins for which the carbon dioxide enhanced oil recovery (CO$_2$-EOR) process has been considered suitable, the CO$_2$ Prophet model was chosen by the U.S. Geological Survey (USGS) to be the primary source for estimating recovery-factor values for individual reservoirs. The choice was made because of the model’s reliability and the ease with which it can be used to assess a large number of reservoirs. The other two approaches—the empirical decline curve analysis (DCA) method and a review of published literature on CO$_2$-EOR projects—were deployed to verify the results of the CO$_2$ Prophet model. This chapter discusses the results from CO$_2$ Prophet (chapter B, by Emil D. Attanasi, this report) and compares them with results from decline curve analysis (chapter C, by Hossein Jahediesfanjani) and those reported in the literature for selected reservoirs with adequate data for analyses (chapter D, by Ricardo A. Olea).

To estimate the technically recoverable hydrocarbon potential for oil reservoirs where CO$_2$-EOR has been applied, two of the three approaches—CO$_2$ Prophet modeling and DCA—do not include analysis of economic factors, while the third approach—review of published literature—implicitly includes economics. For selected reservoirs, DCA has provided estimates of the technically recoverable hydrocarbon volumes, which, in combination with calculated amounts of original oil in place (OOIP), helped establish incremental CO$_2$-EOR recovery factors for individual reservoirs.

The review of published technical papers and reports has provided substantial information on recovery factors for 70 CO$_2$-EOR projects that are either commercially profitable or classified as pilot tests. When comparing the results, it is important to bear in mind the differences and limitations of these three approaches.

Discussion of Recovery Factors with CO$_2$-EOR from Three Sources

The CO$_2$ Prophet model was used to evaluate the potential reservoir performance of the CO$_2$-EOR process using geologic, reservoir, and production data from a comprehensive resource database (CRD) described by Carolus and others (in press). To demonstrate the effectiveness of the model, several CO$_2$-EOR projects—were deployed to verify the results of the CO$_2$ Prophet model. This chapter discusses the results from CO$_2$ Prophet model. This chapter compares them with results from decline curve analysis (chapter C, by Hossein Jahediesfanjani) and those reported in the literature for selected reservoirs with adequate data for analyses (chapter D, by Ricardo A. Olea).

To estimate the technically recoverable hydrocarbon potential for oil reservoirs where CO$_2$-EOR has been applied, two of the three approaches—CO$_2$ Prophet modeling and DCA—do not include analysis of economic factors, while the third approach—review of published literature—implicitly includes economics. For selected reservoirs, DCA has provided estimates of the technically recoverable hydrocarbon volumes, which, in combination with calculated amounts of original oil in place (OOIP), helped establish incremental CO$_2$-EOR recovery factors for individual reservoirs.

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The range of calculated RF values reflects the variations in reservoir heterogeneity as measured by the pseudo-Dykstra-Parsons coefficient, the oil viscosity, and other variables that may affect the RF. For each reservoir, the residual oil saturation ($S_{orw}$) at the initiation of CO$_2$-EOR that was preceded by waterflooding was assumed to be 0.25 (which can also be expressed as 25 percent), because all evaluated reservoir lithologies were clastic. Each reservoir was assumed to have a volume of CO$_2$ equal to 100 percent of the hydrocarbon pore volume (HCPV) injected during EOR. However, additional runs were made to assess the impact of increasing the injection volume to 150 percent of the HCPV, and the results showed an increase of 2.5 to 3.5 percentage points in the RF values. Also, the incremental increases in the RF values due to increased injection are smaller where the value of $S_{orw}$ is smaller.

The DCA evaluation included a total of 15 reservoirs, and the results show that the incremental RF values after CO$_2$-EOR range between 6.6 and 13.8 percent (average 10.9 percent) for the 3 clastic reservoirs and between 7.6 and 25.7 percent (average 13.8 percent) for the 12 carbonate reservoirs, which were mostly dolomites. The results do indicate higher recoveries in carbonate reservoirs compared to clastic reservoirs, but limited data in terms of a smaller number of reservoirs, especially clastic, prevent us from drawing any firm conclusions. Although there were only 15 reservoirs for DCA, their results are found to be within a reasonable range when compared with those from CO$_2$ Prophet modeling.

A review of technical papers and reports included 70 EOR projects located around the world, of both field-wide application and pilot tests, with the majority of them in the United States. The available information indicates that at CO$_2$
injection volumes equivalent to 90 percent of the HCPV, the RF value for EOR was about 16 percent of the OOIP in carbonate reservoirs and 11.5 percent in clastic reservoirs. This RF value for clastic reservoirs (11.5 percent) is falling in the middle of the range of RF values from modeling (9.50–13.43 percent) where each reservoir was assumed to have a CO₂ injection volume equivalent to 100 percent of the HCPV.

Discussion of Some Important Variables That Have Significant Effects on RF Values

The review of technical papers revealed some interesting observations: (1) all other factors being the same, the larger the value of Sorw (oil saturation after waterflooding and prior to application of CO₂-EOR), the higher the RF value and (2) one of the attributes of critical importance in reservoir modeling is the Sorw in those portions of the reservoir thoroughly flushed by the waterflooding. Unfortunately, reported values of Sorw are few despite its importance in CO₂-EOR modeling. The mean values follow closely the default values of 25 percent for clastic reservoirs and 38 percent for carbonate reservoirs used by the National Petroleum Council (NPC, 1984), which later revised the value for carbonate reservoirs to 30.5 percent (Donald J. Remson, National Energy Technology Laboratory, written commun., 2015). The mean values are within the interval of 20 to 35 percent postulated by Tzimas and others (2005). However, the algorithm developed by Hirasa and others (1984, 1989) was used to compute the pseudo-Dykstra-Parsons coefficient. Their algorithm for computing the pseudo-Dykstra-Parsons coefficients resulted in a range in values between 0.5 and 0.98. Due to limitations of the CO₂ Prophet software, the maximum effective value of the pseudo-Dykstra-Parsons coefficient was 0.86 (J.K. Dobitz, Windy Cove Energy, written commun., 2015), and, therefore, the calculated values resulting from the algorithms of Hirasa and others (1989) that exceeded 0.86 were set to 0.86.

References Cited


