Predicting CO₂ Residual Trapping Ability Based on Experimental Petrophysical Properties for Different Sandstone Types

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Abstract

CO₂ storage in deep geologic formations is a necessary method to address the climate change problem. To ensure long-term security of the injected CO₂, a better prediction of the post-injection CO₂ residual trapping amount is needed. Not only is residual trapping the fastest-acting secondary trapping mechanism during the post-injection plume-migration stage, but this trapping mechanism can also immobilize significant amount of CO₂ [1]–[3]. Using CO₂/water coreflooding experimental methods, we seek to characterize and predict the CO₂ residual trapping ability of different rock types based on their petrophysical properties.

Just like porosity, permeability and other rock petrophysical properties, it has been shown that a rock type’s residual trapping ability is also an inherent property that does not change over a wide range of temperature, pressure, and brine salinity [4]. Many previous studies have explored what factors affect the absolute amount of nonwetting phase residual trapping within a single rock core, and it has been concluded that the amount of residual trapping depends on the interplay of capillary, viscous, and gravity forces, and therefore is affected by wettability, capillary number, Bond number, gravity number, and viscosity ratio numbers [5]–[11]. However, few studies have looked at what factors affect CO₂ residual trapping ability across different types of reservoir sandstones specifically in the context of CO₂ geologic storage where the water imbibition flow regime is capillary-dominant. Therefore, this study focuses on how CO₂ residual trapping ability differs for different rock types and why that is.

A rock core’s residual trapping ability is defined by the coefficient in its trapping relationship. Among the many parametrized trapping relationships, Land’s trapping relationship and the linear trapping relationship are the most commonly used [12], [13]. Therefore, a rock core’s residual trapping ability can then be determined by the value of the Land’s trapping coefficient or the linear trapping coefficient. By conducting CO₂/water coreflooding experiments at reservoir conditions on core samples with different degrees and types of heterogeneity, we are able to extract accurate petrophysical properties such as porosity, permeability, degree of subcore-scale heterogeneity, as well as correlation length in different directions. We are also able to correlate these rock properties with their corresponding residual trapping abilities to gain insights into which petrophysical parameters are the most influential and therefore are the best predictors for a rock core’s residual trapping ability.

Sandstone types experimented on include Bentheimer, Dundee, Fontainebleau, Heletz, and two types of Berea: Liver and Split. For the two types of Berea sandstone, experiments have also been done on both cores with lamination parallel to flow and cores with lamination perpendicular to flow.
to see whether lamination direction significantly affects CO₂ residual trapping ability. Experimental results show that CO₂ residual trapping ability correlates well with porosity, but it also correlates well with parameters that represent degree of heterogeneity, such as the pore size distribution index in the fitted Brooks-Corey capillary pressure model, the maximum standard deviation in the CO₂ drainage saturation field, and the permeability field Dykstra-Parson coefficient. From the experiments, CO₂ residual trapping ability increases with degree of heterogeneity and decreases with porosity. In addition, lamination direction does not appear to have a significant effect on CO₂ residual trapping ability for the two sets of Berea sandstones tested.

It is expected that residual trapping would increase with degree of heterogeneity because CO₂ snap-off trapping is promoted by heterogeneous pore aspect ratio and CO₂ bypass trapping is promoted by millimeter-scale capillary barriers with high capillary entry pressure contrast. However, the reason behind the correlation between residual trapping ability and porosity is less clear. Because the porosity measured in this study is obtained from a medical CT scanner that measures strictly effective or connected porosity, one hypothesis may be that higher connected porosity regions have better connected pores with an aspect ratio that is less favorable to snap-off. Hence, CO₂ is less likely to be trapped when porosity is higher. Previous studies have shown lamination direction to have a significant effect on CO₂ residual trapping results [14], [15]. The same effect has not been observed with the Berea sandstone and one likely reason is that the laminations are not heterogeneous enough to allow more CO₂ bypass trapping when flow is perpendicular to the lamination planes. To conclude, the best predictors for CO₂ residual trapping ability are porosity and degree of heterogeneity while correlation length and lamination direction are not factors with significant influence in this study.

References


