SOCIETY OF EXPLORATION GEOPHYSICISTS

ROLE OF GEOSCIENCES IN CARBON STORAGE
19-21 March 2024
Mumbai, India

Challenges in permeability prediction concerning geological carbon sequestration: A case study from Ankleshwar oil field, India

Uma Vadapalli, Ajay Malkoti and Nimisha Vedanti*
**umavadapalli@ngri.res.in*

Introduction

Storing large quantities of CO_2 in geological formations like deep saline reservoirs, aquifers, or confined volcanic formations is a favored method for mitigating climate change. The storage efficiency is determined by the porosity, while the effectivity of the injection is controlled by the permeability of the formations. The reactive nature of CO_2 leads to either precipitation or dissolution processes. The initiation of either of the processes depends on the prevailing thermo-physical and chemical conditions. The precipitation can lead to a considerable reduction (~15%) in storage capacity (~porosity), and, in the case of saline aquifers, it can lead to about an 80% drop in permeability (Miri and Hellevang, 2016; Falcon-Suarez et al., 2020). Permeability reduction leads to clogging, especially around the injection well, and thereby causes serious concerns for maintaining the injection efficiency. Thus, monitoring site-specific permeability variations around the injection well is a top priority at geological carbon sequestration (GCS) sites. For determining the site-specific permeability around the injection well, non-invasive monitoring is preferred for safety and feasibility. Since non-invasive direct-permeability measurements are impractical, alternative ways of predicting permeability from either porosity logs or pore size distribution obtained from neutron magnetic resonance (NMR) are preferred. The methods of permeability prediction should be accurate enough to capture any injection-related alterations in permeability. For this, the prediction methods need to represent the pore network realistically. The drawbacks in representing the pore network will lead to erroneous permeability estimation and pre- to post-precipitation permeability ratio, representing the clogging.

Apart from the site-specific permeability, the lateral variations in the field-scale permeability of a formation play a crucial role in determining the CO_2 movement and the most probable and least probable flooding zones. Thus, it is essential to know the field-scale permeability variations in the formations targeted for GCS. This study uses the Fractal theory-based Acceptance Rejection Monte Carlo (FARMC) algorithm, which is suitable for predicting site-specific and field scale permeability (Vadapalli et al., 2022). We applied the FARMC algorithm for observing permeability variations and predicting the probable direction CO_2 will take if it is injected into the reservoir formations of Ankleshwar. The Ankleshwar reservoir was considered a candidate for CO_2-enhanced oil recovery (EOR); however, it was found to have less economic feasibility than the Mumbai high field. Being ignored for CO_2-EOR, Ankleshwar reservoir could be a good candidate for GCS due to its anticlinal structure with a perfect seal, which is best suited for CO_2 storage.

Theory and/or Method

The FARMC algorithm simulates the mono-fractal distribution of pores and their tortuous capillary tubes for a realistic representation of the pore network in the porosity range of 10-35% for sandstones and shaly sands (Vadapalli et al., 2022). The method follows an error minimization scheme to attain stability by removing initialization bias and correlation effects in the Monte Carlo simulation for a repeatable permeability prediction. The verification of the algorithm over the measured permeability of core samples infers that this algorithm predicts permeability within one-order magnitude bounds for clean and shaly-sand zones, in which macro porosity is the major contributor to permeability. However, the method gives overestimates for low permeability sandstones composed of carbonate minerals, which are probably the precipitates. The low permeability of such formations is due to ultra-small pores, which mainly contribute to microporosity and can be described by multifractal theory (Jiang et al., 2018). Thus, in low permeability formations such as sandstones altered due to precipitation, considering microporosity and a multifractal approach is essential for reliable permeability estimation because multifractal geometry can effectively determine effects of localized alterations/precipitations on pore network and the global property such as permeability (Xu et al., 2023).

Obtaining permeability from Well logs can provide more information for a comprehensive description of fluid flow in a reservoir than sparse measurements obtained from core samples or pressure dropdown/buildup tests in a well. Thus, we obtained permeability variations utilizing Well logs in nine wells, passing through the Ankleshwar reservoir's six pay sands (S_{C-1} to S_{C-6}). The obtained site-specific permeability variations in the Wells are used to estimate the reservoir quality index and the permeability maps of each pay sand of the reservoir.

Examples

The permeability map of the pay sand S_{C-2} is shown in Figure 1. The map shows significant lateral variations in permeability in this pay sand, with a high permeability zone towards the east. In other pay sands, we have also observed a common high-permeability trend towards the east.

Conclusions

The mono fractal theory-based algorithm predicts reliable permeability of the formations, where the major contribution to permeability is through wider macro pores. However, in altered sandstones with ultra-small pore size distribution, a multifractal

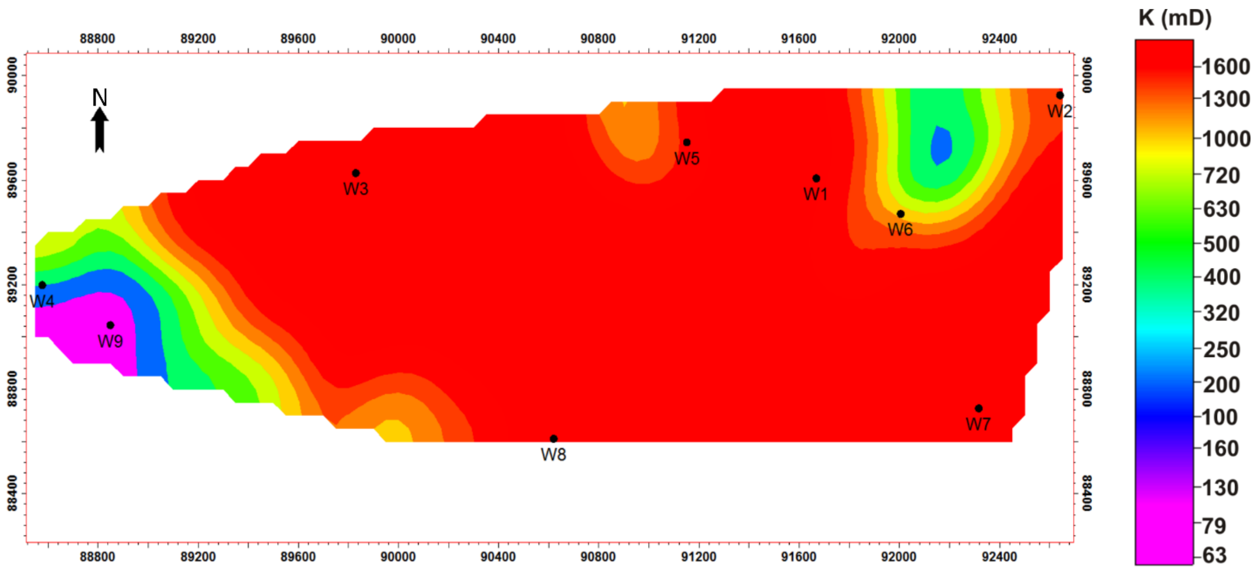

Figure 1: The map showing lateral variations in the permeability of the S_{C-2} pay sand in the Ankleshwar reservoir. There is a high permeability trend towards the east. Thus, the injected CO_2 would prioritize moving towards the east.

approach is required to capture small variations in permeability. In the GCS process, CO_2-induced precipitation effects would narrow the pore diameters, resulting in ultra-small pore size distribution. Thus, we suggest applying a multifractal approach to address such permeability alterations.

In the pay sands of the Ankleshwar reservoir, there are significant lateral variations in the permeability, which would affect the CO_2 movement in them if Ankleshwar is considered a candidate for GCS. Depending on the lateral permeability variations, we infer that CO_2 prioritizes moving towards a high-permeability trend east of the study area, as shown in Figure 1. However, the interplay of the geological dip, which controls buoyancy and discontinuities, which can obstruct CO_2, would also play an important role in determining fluid movement direction in a reservoir. Thus, such information needs to be integrated with permeability variations before conforming the direction of CO_2 movement in the Ankleshwar reservoir. Such a study would become more informative or reliable if 3D seismic data, which can provide the area's detailed geological structure, is available.

References

1. Falcon-Suarez, I. H., Livo, K., Callow, B., Marin-Moreno, H., Prasad, M., & Best, A. I. (2020). Geophysical early warning of salt precipitation during geological carbon sequestration. *Scientific Reports*, *10*(1), 16472.
2. Miri, R., & Hellevang, H. (2016). Salt precipitation during CO2 storage—A review. *International Journal of Greenhouse Gas Control*, *51*, 136-147.
3. Jiang, Z., Mao, Z., Shi, Y., & Wang, D. (2018). Multifractal characteristics and classification of tight sandstone reservoirs: A case study from the Triassic Yanchang Formation, Ordos Basin, China. *Energies*, *11*(9), 2242.
4. Vadapalli, U., Malkoti, A., Vedanti, N., Dimri, V. P., & Guruhappa, H. (2022). Field-scale and site-specific permeability of sandstone reservoirs using a stabilized Monte Carlo algorithm: A case study. *Geophysics*, *87*(6), B337-B350.
5. Xu, S., Xia, Y., Lu, M., Wei, W., Wang, L., & Cai, J. (2023). Fractal Perspective on the Effects of the Acid–Rock Interaction on the Shale Pore Structure. *Energy & Fuels*, *37*(9), 6610-6618.
6. Bokka, H. K., Zhang, K., & Lau, H. C. (2022). Carbon capture and storage opportunities in the west coast of India. Energy Reports, 8, 3930-3947.

Acknowledgments

The authors thank ONGC Ltd. for providing data utilized in the study. This work was part of the Indo-Norwegian project sponsored by the Royal Norwegian Embassy in New Delhi. This support for the study is highly acknowledged. We thank the director of NGRI for permitting us to present the work.