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Posted Date: 26 June 2024

doi: 10.20944/preprints202406.1849.v1

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Concept Paper

An Initial Approach of Multiple Linear Regression in CO₂-Water Relative Permeability Prediction for Carbon Storage Projects

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Abstract: This work discusses the feasibility of multiple linear regression in predicting water/CO₂ relative permeability using training and testing datasets from two nearby wells, separately, of the Lower Cretaceous Lakota Sandstone, Jurassic Hulett Sandstone, and Pennsylvanian Minnelusa Formation at the Dry Fork Station site. The outcome is promising as the predicted and measured relative permeability data are decently comparable. Yet, whether this approach could be generally applicable needs more delicate models and larger training datasets to be determined.

Keywords: CCUS; relative permeability; supervised learning

1. Introduction

Class VI well (EPA, 2013) requires site characterization and prediction of the extent of the injected CO₂ plume and associated pressure front, whichever is further defined as Area of Review. The Area of Review is identified via dynamic modeling, which is highly sensitive to the CO₂-water relative permeability of the injection formation. This work discusses the potential of the previously published relative permeability data of the injection formations (Yu et al., 2023) at one well to be applied to another nearby well. This approach might be useful for projects with limited sources of the special core data for dynamic modeling—relative permeability of the aquifer formations between water and CO₂.

2. Method

This work uses multiple linear regression to determine the dependent variable crosspoint saturation (CS_w) of water and CO₂ relative permeability curves from the irreducible water saturation (Sw_i) and true reference cross-point saturation (RCS). The first independent variable Sw_i is a decimal that has the range of 0–1. To constrain this range, another variable, true reference cross-point saturation (RCS) is also introduced. RCS has a physical meaning and is half of the dynamic space (Mirzaei-Paibaman, 2021):

$$RCS = 0.5 \times (1 - Sw_i) \quad (1)$$

The multiple linear regression is defined as:

$$CS_w = w_1 \cdot Sw_i + w_2 \cdot RCS + b \quad (2)$$

w_1 , w_2 , and b are fitting parameters. This work has limited core data from two CO₂ injection wells, PRB#1 and PRB#2, for three potential storage reservoirs—the Lower Cretaceous Lakota Sandstone, Jurassic Hulett Sandstone, and Pennsylvanian Minnelusa Formation—at the Dry Fork Station site, where PRB#1 data (Yu et al., 2023) is for training, and PRB#2 data is for testing. Both PRB#1 and PRB#2 relative permeability data were acquired with the unsteady-state method (Johnson et al., 1959). Modified Brooks and Corey model (MBC (Behrenbruch & Goda, 2006) is adopted for the relative permeability curve fitting:

$$krw = krw_{max} \cdot \left(\frac{Sw - Sw_i}{Sw_{max} - Sw_i} \right)^{n_{water}} \quad (3)$$

$$kr_g = kr_{g_{max}} \cdot \left(\frac{S_{w_{max}} - S_w}{S_{w_{max}} - S_{w_i}} \right)^{n_{gas}} \quad (4)$$

Where $S_{w_{max}} = 1$ for the CO₂ injection into the aquifer scenario. For this application, the crosspoint CS_w serves to determine the index n_{water} and n_{gas} for the predicted curves. Thus, only the endpoint S_{w_i} needs to be figured out for a certain core sample, which is the purpose and expectation of the work, while the limitations are concluded in the last section. Refer to the Appendix for the coding. Independent and dependent variables are tabulated in Table 1.

Table 1. Relative permeability data for training and testing.

Well	Sample No.	S_{w_i}	RCS	CS_w
PRB#1	Lakota 8031.4	0.540999	0.2295	0.770701
	Lakota 8035.4	0.580368	0.209816	0.787591
	Hulett 8307.7	0.46972	0.26514	0.74372
	Hulett 8325.8	0.579942	0.210029	0.817819
	Hulett 8332.6	0.526892	0.236554	0.712748
	Minnelusa 9366.8	0.406033	0.296984	0.652225
	Minnelusa 9464.2	0.416358	0.291821	0.747614
PRB#2	Minnelusa 9529.3	0.491233	0.254384	0.725876
	Lakota 8063	0.59199	0.204005	0.77327
	Hulett 8330	0.521616	0.239192	0.766865
	Minnelusa 9487	0.409992	0.295004	0.681677

3. Result and Discussion

The predicted CS_w is listed in Table 2. The mean absolute percentage errors (MAPE) of the samples Lakota 8063, Hulett 8330, and Minnelusa 9487 are 2.94%, 1.39%, and 1.67%, respectively, considered insignificant. Further, the relative permeability curve expression is displayed in Figure 1.

Table 2. Measured and predicted crosspoint saturation CS_w used for relative permeability expression.

Well	Sample No.	S_{w_i}	RCS	CS_w	Predicted CS_w
PRB#2	Lakota 8063	0.59199	0.204005	0.77327	0.79602105
	Hulett 8330	0.521616	0.239192	0.766865	0.75620107
	Minnelusa 9487	0.409992	0.295004	0.681677	0.69304051

The predicted CS_w and relative permeability expression are agreeably similar and feasible for dynamic modeling from a practical perspective. This suggests that the irreducible water saturation serves as a critical indicator for the rock's wettability, which dominates the fluid flow in porous media and might even neglect the petrophysical barriers of varying formations at the studied site. Yet, as the training and testing datasets used for this work are limited, this approach using irreducible water saturation (S_{w_i}) and reference crosspoint saturation (RCS) to predict the crosspoint saturation (CS_w) and further relative permeability curves of the injection formations at the nearby wells might only be applicable to this project. More delicate models and approaches should be requested for similar applications to assist the carbon storage projects efficiently and accurately.

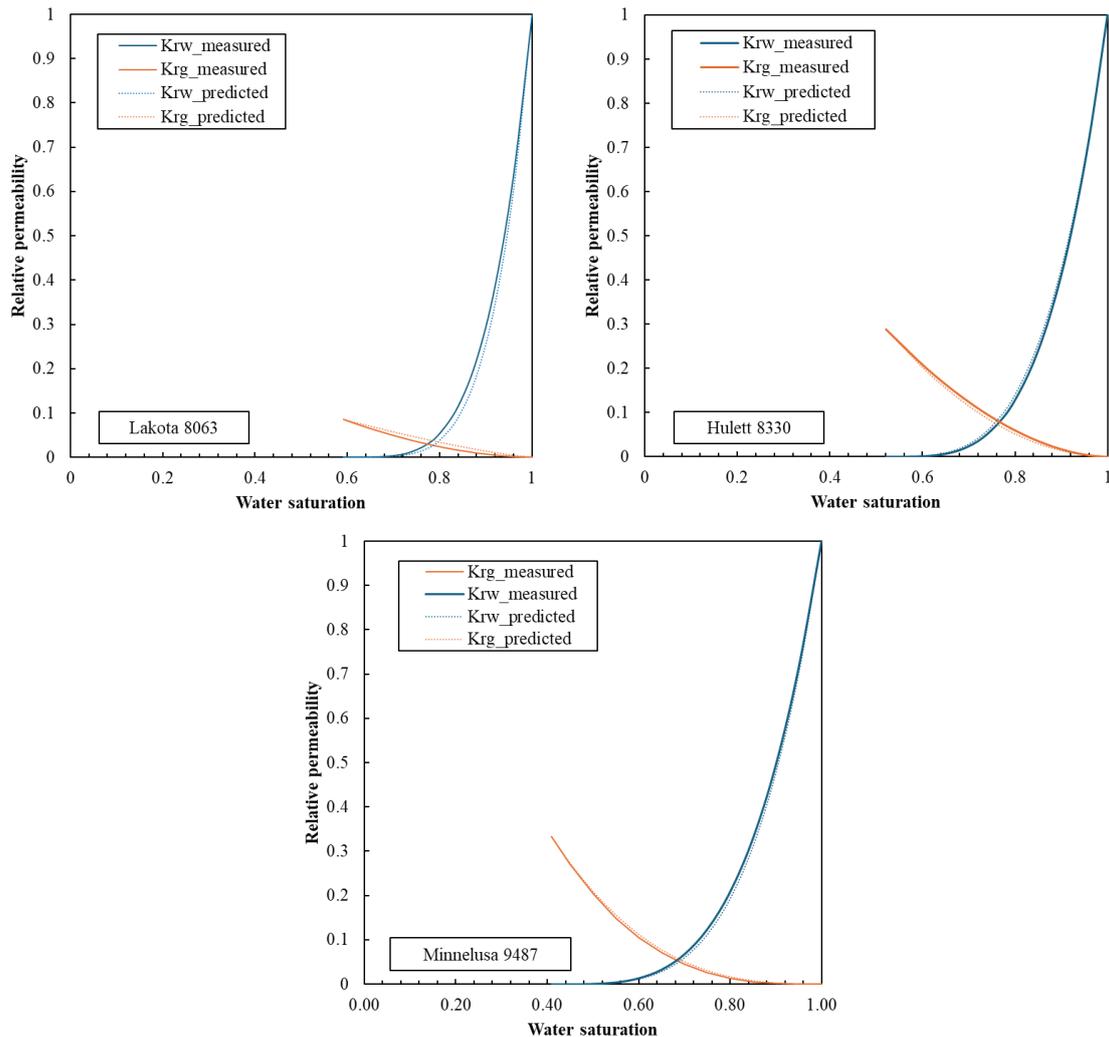


Figure 1. Measured and predicted relative permeability comparison.

4. Conclusion

This work discusses the feasibility of multiple linear regression in predicting water/CO₂ relative permeability using training and testing datasets from two nearby wells, separately, of the Lower Cretaceous Lakota Sandstone, Jurassic Hulett Sandstone, and Pennsylvanian Minnelusa Formation at the Dry Fork Station site. The outcome is encouraging as the predicted relative permeability data is usable for dynamic modeling from a practical standpoint at the study site. Meanwhile, whether this approach could be generally applicable needs more delicate models and larger training datasets to be determined.

Appendix

Multiple linear regression code is published on GitHub (<https://github.com/yuyu84310/MLR-for-CCUS-relative-permeability-prediction>).

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