Integrating Rock Quality Index (RQI) for Enhanced Relative Permeability Estimation in Heterogeneous Reservoirs: A Preliminary Analysis

Justice C. Osuala and Russell T. Johns

John and Willie Leone Family Department of Energy and Mineral Engineering, The Pennsylvania State University

Background

Accurately estimating relative permeability (kr) requires a comprehensive understanding of the fluid and rock properties that influence its behavior. Traditionally, kr has been quantified as a function of phase saturation. However, recent studies show that kr also depends on factors such as phase connectivity, wettability, capillary number, and fluid-fluid interfacial area.

A key limitation in past studies is the assumption of constant pore structure when estimating kr, despite the heterogeneous and anisotropic nature of porous media. This research seeks to bridge this gap by integrating the Rock Quality Index (RQI) to better account for variations in pore structure and improve kr estimation in complex reservoir conditions..

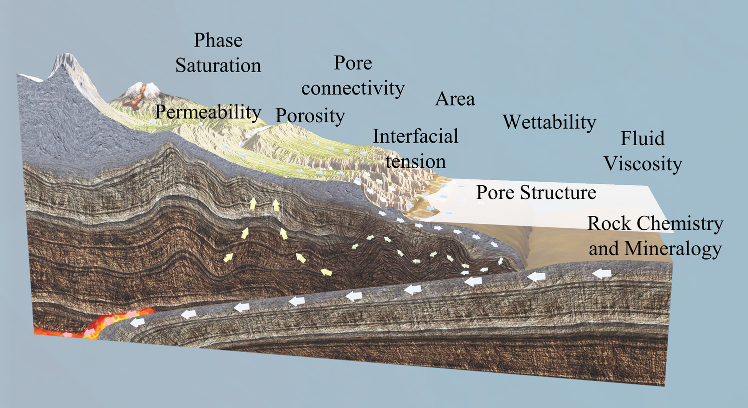

Fig . 1 – Rock and fluid properties that impact the physics of relative permeability.

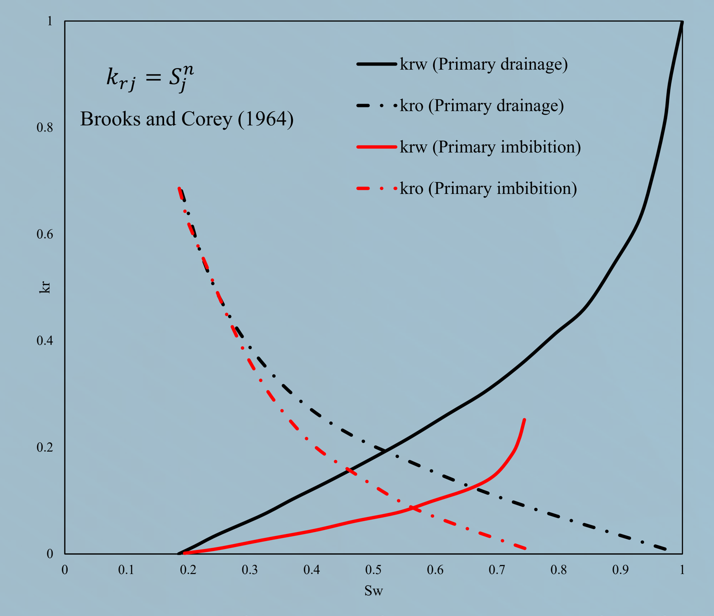

Fig. 2 – Schematic showing water-oil relative permeabilities for a water-wet medium. Hysteresis in relative permeabilities is also displayed.

Objectives

- Incorporate pore structure in estimating relative permeability, showing relative permeability as a state function of saturation, connectivity, and pore structure
- Explore that RQI is an effective parameter in quantifying pore structure
- Show the changes of fluid and rock properties of physical interest with RQI at extreme cases.

Relative Permeability Equation of State

$$dkrj = \frac{\partial kr_j}{\partial S_j} dS_j + \frac{\partial kr_j}{\partial \mathcal{X}_j} d\mathcal{X}_j + \frac{\partial kr_j}{\partial A_j} dA_j + \frac{\partial kr_j}{\partial \theta_j} d\theta_j + \frac{\partial kr_j}{\partial \mu_j} d\mu_j + \frac{\partial k_j}{\partial k} dk + \frac{\partial kr_j}{\partial \Phi} d\Phi + \frac{\partial k_j}{\partial Ij} dI_j + \frac{\partial kr_j}{\partial g} dg + \frac{\partial kr_j}{\partial \lambda} d\lambda + \frac{\partial kr_j}{\partial \zeta} d\zeta$$

Eqn. 1 – Conceptual EOS for relative permeability

$$dkrj = \frac{\partial kr_j}{\partial S_j} dS_j + \frac{\partial kr_j}{\partial \hat{\chi}_j} d\hat{\chi}_j + \frac{\partial kr_j}{\partial I_j} dI_j + \frac{\partial kr_j}{\partial Nca} dNca + \frac{\partial kr_j}{\partial \lambda} d\lambda$$

Eqn. 2 – Khorsandi et al. (2017)

$$dkrj = \frac{\partial kr_j}{\partial S_j} dS_j + \frac{\partial kr_j}{\partial \hat{\chi}_j} d\hat{\chi}_j$$

Eqn. 3 – Purswani et al. (2019)

$$dkrj = \frac{\partial kr_j}{\partial S_j} dS_j + \frac{\partial kr_j}{\partial \hat{\chi}_j} d\hat{\chi}_j + \frac{\partial kr_j}{\partial \lambda} d\lambda$$

Eqn. 4 – Current approach

S_j is saturation of phase j

$\mathcal{X}_j$ is pore connectivity

A_j is the rock flow area

θ_j is the rock wettability

μ_j is the phase viscosity

k is the rock permeability

Φ is porosity

I_j is the interfacial tension

g is gravity

λ is the pore structure

ζ depicts the rock chemistry

Methods and Results

$RQI = \sqrt{\frac{k}{\Phi}}$ *Where k is rock permeability and Φ is porosity*

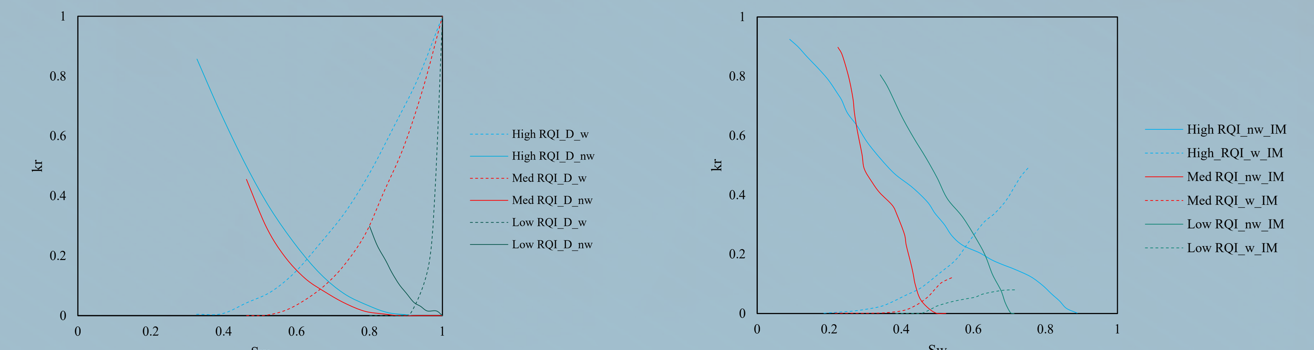

Fig. 3 – Disparities in kr and residual saturations with RQI during drainage and imbibition. Data after Leila et al 2021

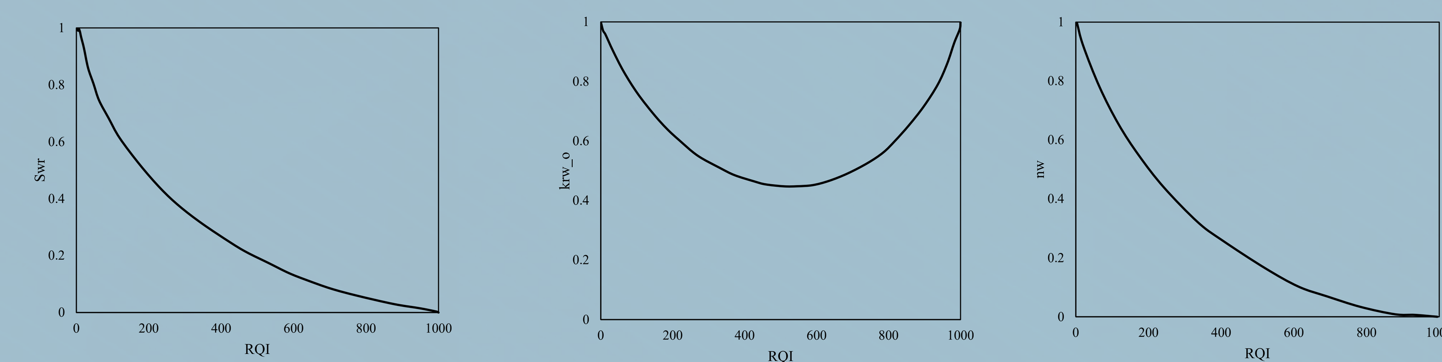

Fig. 4 – Illustration of changes of residual water saturation, maximum relative permeability of water, and Corey exponent for water, respectively at zero to infinite RQI .

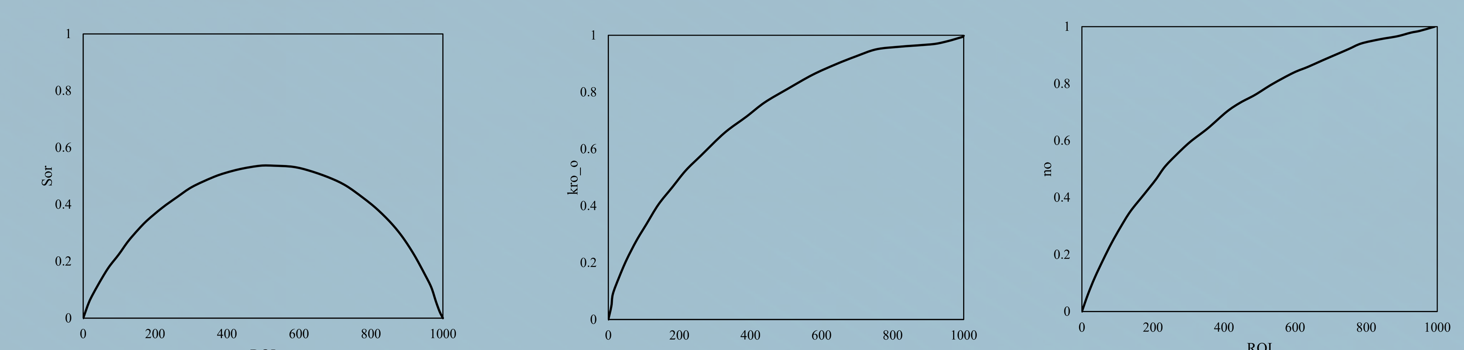

Fig. 5– Illustration of changes of residual oil saturation, maximum relative permeability of oil, and Corey exponent for oil, respectively at zero to infinite RQI .

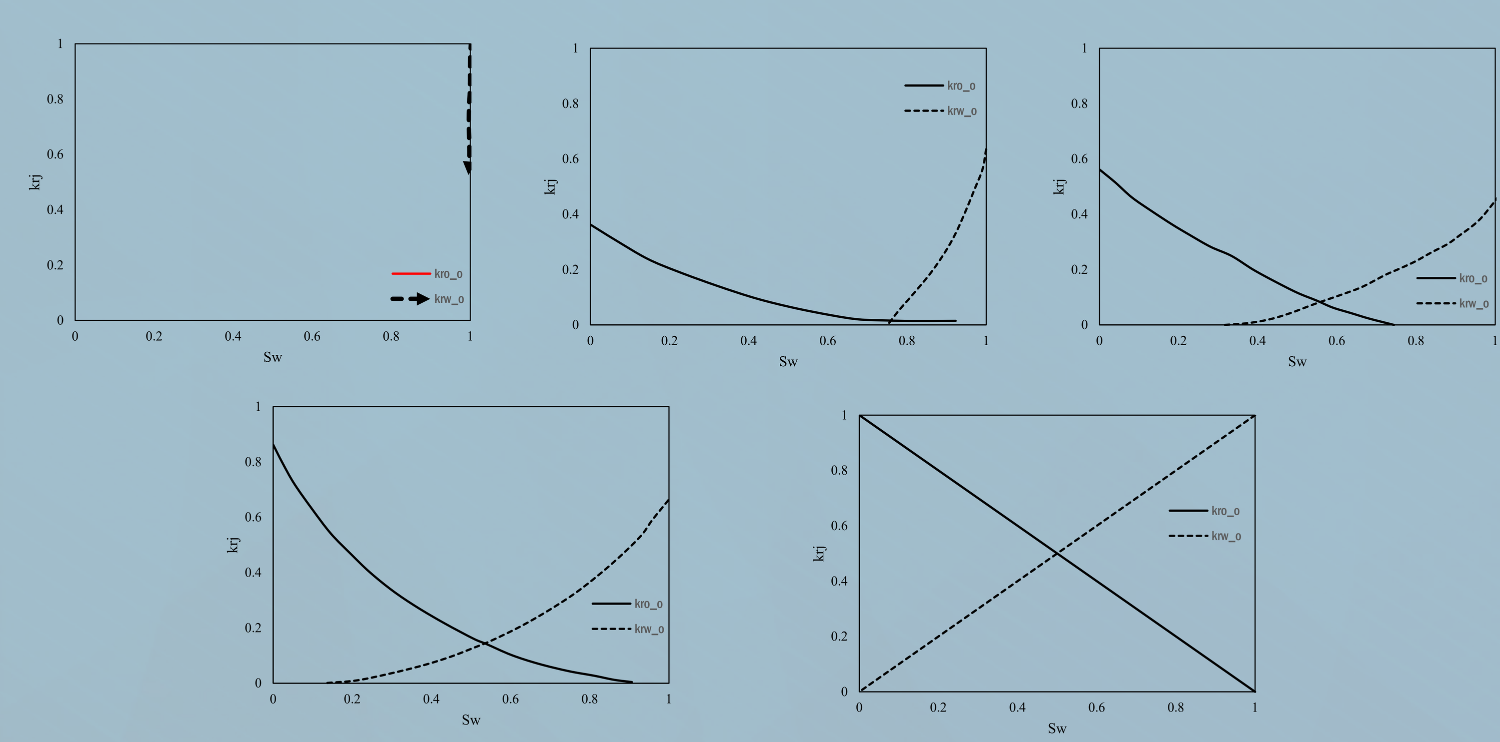

Fig. 6 – Illustration of relative permeability curves for a zero, low, medium, high, and infinite RQI cases, respectively.

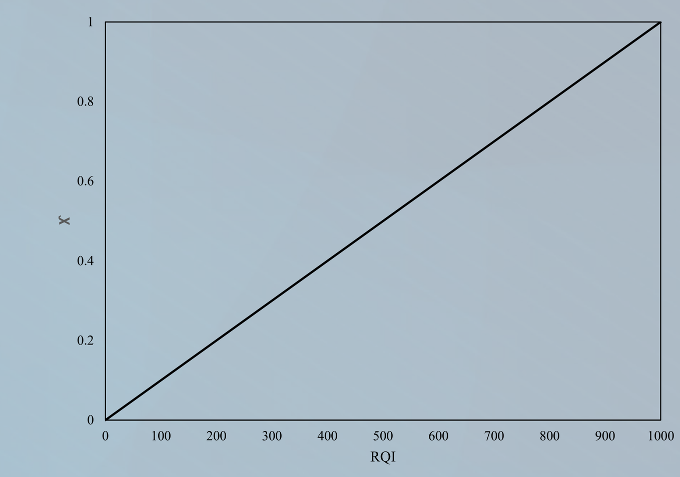

Fig. 7 – Illustration of changes in normalized pore connectivity with zero to infinite RQI

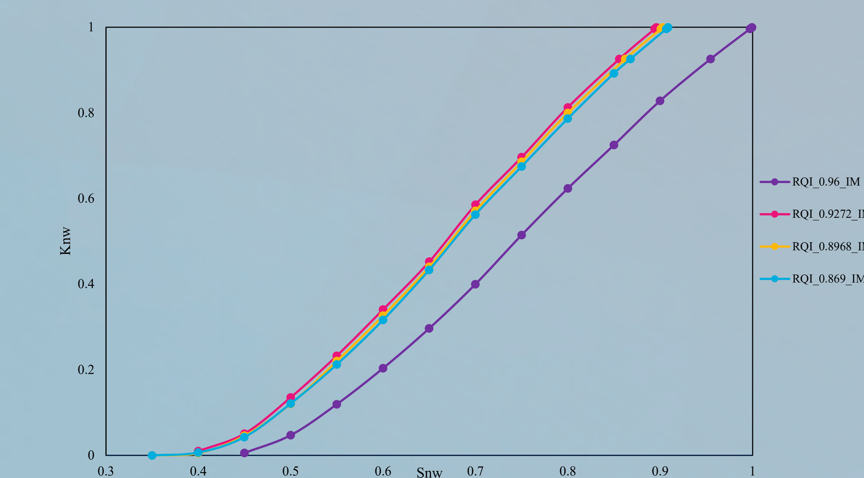

Fig. 8 – Comparison of residual oil saturations using results from Pore Network Modeling data evaluation.

Conclusion

- RQI is an easy and effective quantitative measure for characterizing pore structure.
- Graphical illustrations have been used to validate physical relationship between RQI and relative permeability.
- Rock porous media heterogeneity and complexity while estimating relative permeability can be accounted for by rigorously studying RQI as a representation of pore structure.

References

Khorsandi, S., Li, L., & Johns, R. T. (2017). Equation of State for Relative Permeability, Including Hysteresis and Wettability Alteration. SPE Journal, 22(06), 1915–1928. https://doi.org/10.2118/182655-PA

Purswani, P., Johns, R., Karpyn, Z., et al 2021. Predictive Modeling of Relative Permeability Using a Generalized Equation of State. SPE Journal 26 (September). https://doi.org/10.2118/200410-PA.

Acknowledgements

Thanks to my advisor Dr. Russell T. Johns who holds the George E. Trimble Chair in Earth and Mineral Sciences at Penn State University.

PennState College of Earth and Mineral Sciences

John and Willie Leone Family Department of Energy and Mineral Engineering