Relative Permeability for Water and Gas Through Fractured Cement

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INTRODUCTION

Multiphase permeability is a critical parameter in understanding of flow in subsurface environments where well drilling, for operations such as deep carbon capture, oil and gas production, or geothermal energy production are employed. Typically research of relative permeability focus on the natural rock media, including both porous and fractured rock where fracturing will occur from subsurface geomechanical processes. However, cement used in the wellbore annulus is subject to the same environmental stress that result in fractured rock increasing risk of leakage through wellbores. This study attempts to quantify relative permeability of brine and air through fractured Ordinary Portland Cement (OPC), while applying resistivity measurements for monitoring the effective saturation of fractures.

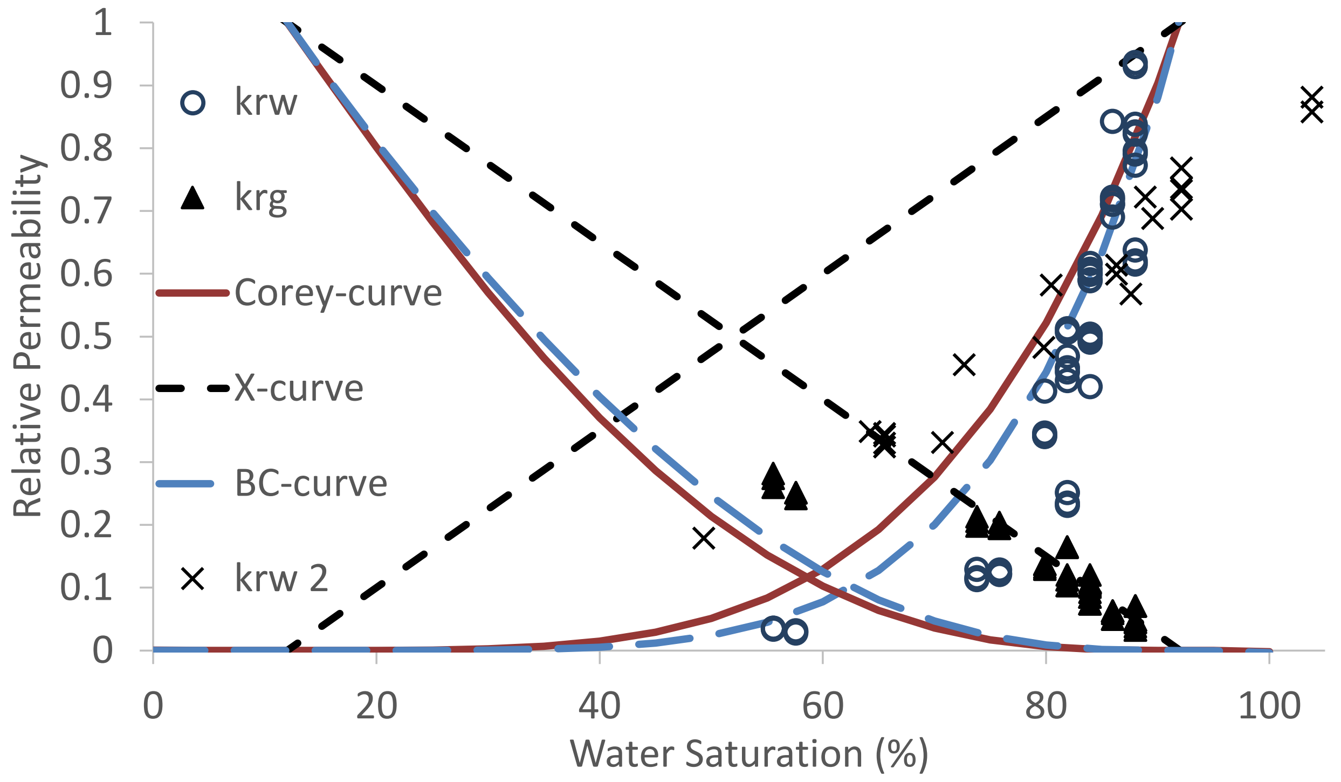

Figure 4. Relative permeability plot of simple fracture core with horizontal orientation

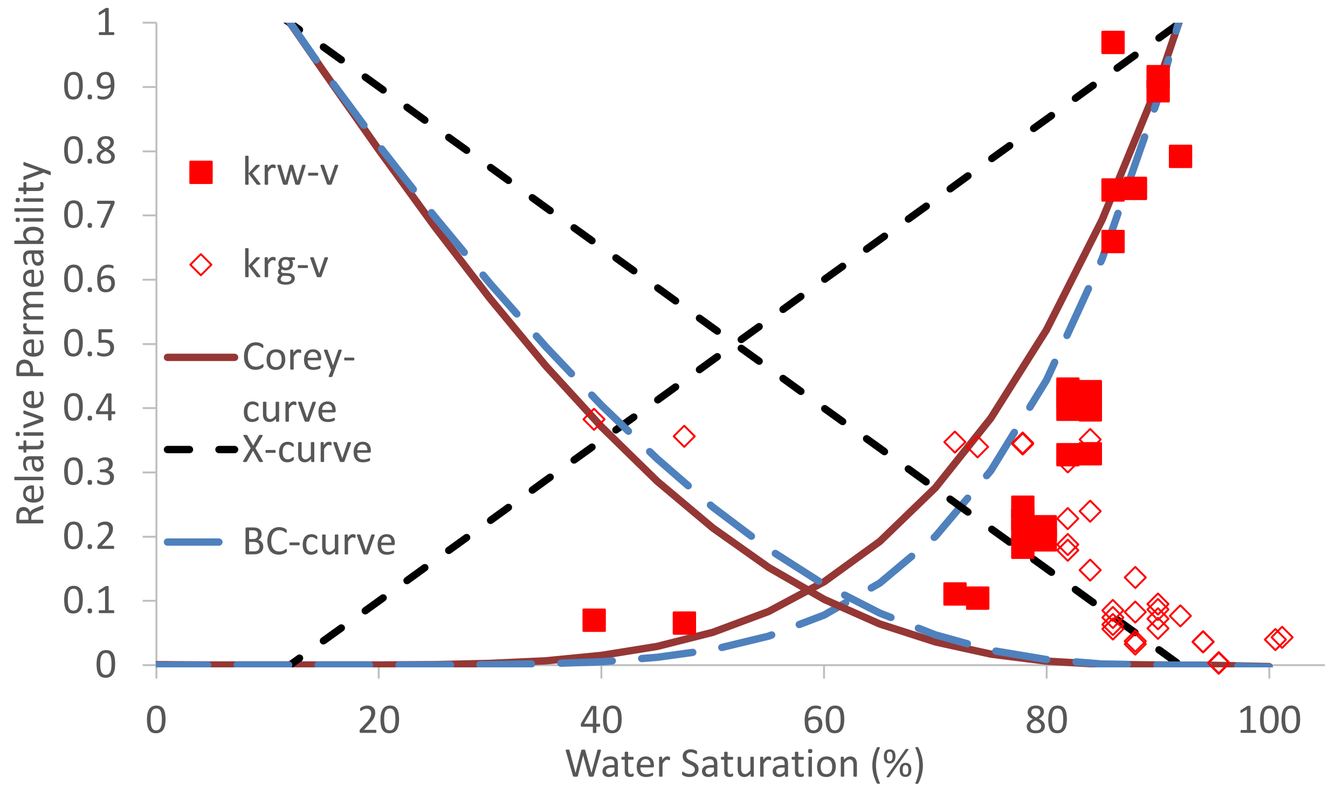

Figure 5. Relative permeability plot of simple fracture core with vertical orientation

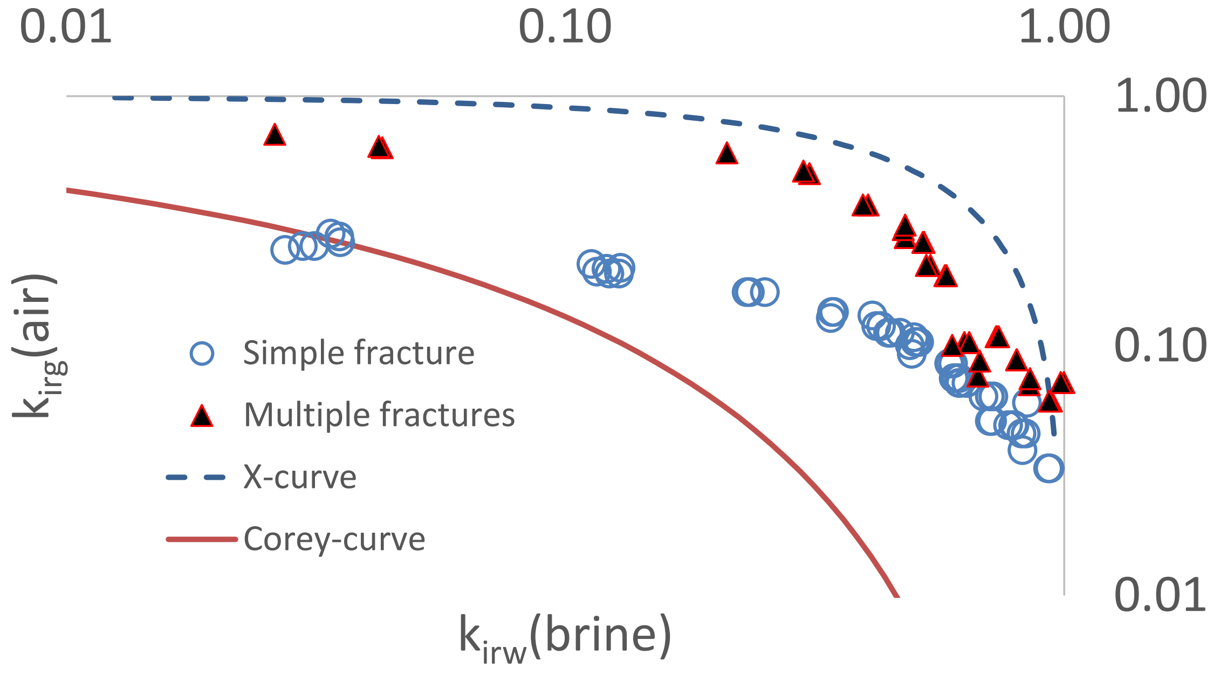

Figure 6. Log-log plot of k_{irg} (air) to k_{irw} (brine)

$$Q = -\frac{Wb^3}{12\mu}\left(\frac{P_i - P_o}{L}\right)$$ *Eqn 1*

$$k_i = \frac{b^2}{12}$$ *Eqn 2*

Q = discharge ($cm^3\ s^{-1}$)
W = effective fracture width (cm)
b = effective fracture aperture (cm)
μ = viscosity (Pa·s)
P_i = pressure at inlet (Pa)
P_0 = pressure at outlet (Pa)
L = fracture length (cm)
k_i = permeability (cm^2)

$$Q_w = \frac{k_i k_{irw} A(P_i - P_o)}{\mu_w L}$$ *Eqn 3*

$$Q_g = \frac{k_i k_{irg} A\left(P_i^2 - P_o^2\right)}{\mu_g L P_o}$$ *Eqn 4*

Q_w = discharge water ($cm^3\ s^{-1}$)
Q_g = discharge gas ($cm^3\ s^{-1}$)
A = area of channel (cm^2)
μ_w = viscosity water (Pa·s)
μ_g = viscosity gas (Pa·s)
k_{irw} = relative permeability water (cm^2)
k_{irg} = relative permeability gas (cm^2)

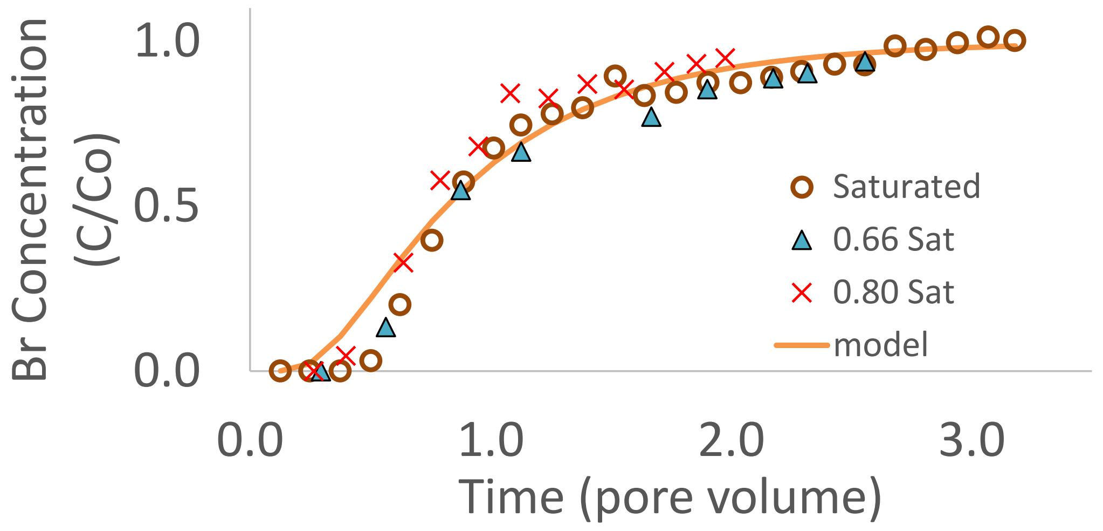

Figure 7. tracer through simple fracture, 100%, 80%, and 66% fracture saturations; ADE model of 100% saturated shown.

- Velocity cm s^{-1}: 100% sat = 1.6; 80% sat = 1.0; 66% sat = 0.6
- Dispersion Coefficient $cm^2\ s^{-1}$: 100% sat = 3.7; 80% sat = 2.2; 66% sat = 0.9

MATERIALS AND METHODS

•Cement monoliths

•OPC 5.08 cm diameter, 10 cm long; cured: 100% RH for 28 days

•wrapped with 3" heavy duty moisture-seal heat-shrink tubing.

•fracture: hydraulic press apply force of 100-200 lbs

•pore volume of fractures measured weight change of water imbibe

•XCT and Fracture Segmentation

•scanned using a high-resolution micro focus XCT scanner (Figure 1)

•code for automated fracture segmentation written in Python 2.7

•Fracture dimensions determined MAGICS (Figure 2)

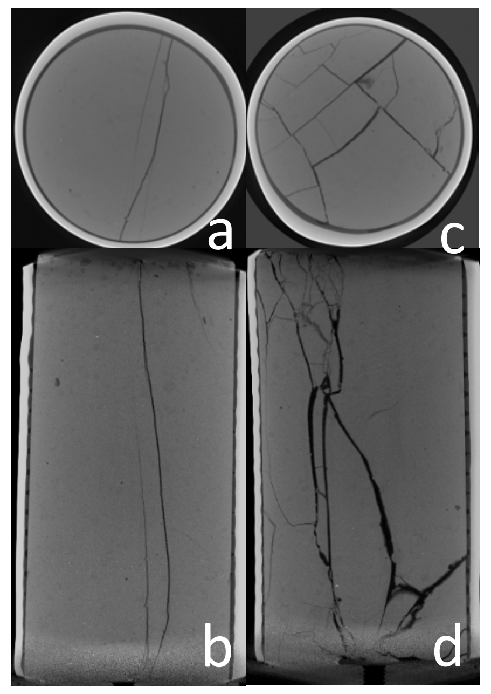

Figure 1. XCT cross section (a, c) and profile (b, d) of cement monolith simple fracture (a, b) and multiple fractures (c, d).

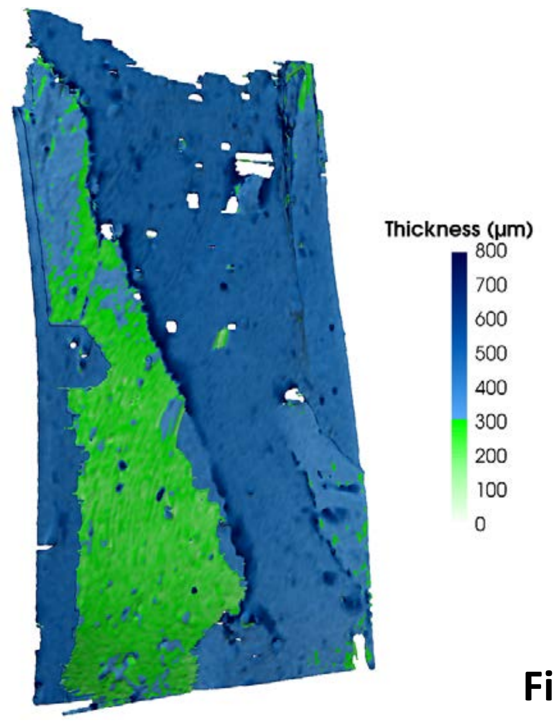

Figure 2. Computationally segmented fracture from simple fracture monolith

•Resistivity measurements

•Calibrations performed under flowing conditions using 0.1M $NaNO_3$ brine

•Resistivity recoded for each relative permeability test, used to determine effective saturation of fracture

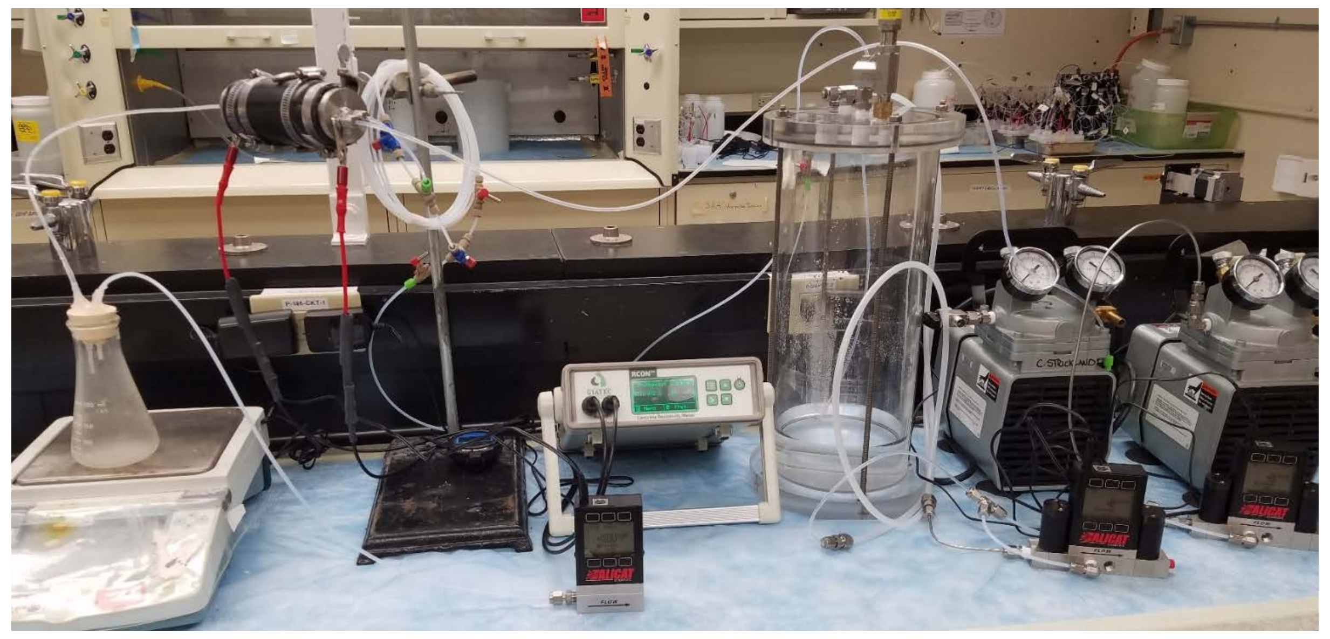

Figure 3. Experimental set up used in this study. Components include: two air pumps, two precision air flow regulators, air flow meter, scale, beaker, tube coil for tracer, water vessel, RCON2 electrical resistivity device, and monolith with stainless steel end caps.

•Permeability and Tracer

•absolute permeability with 0.1M $NaNO_3$ brine, (Figure 3), effective aperture calculated: eqn 1 (0.2 mm for simple fracture); k_i from eqn 2

•Pressure 7-19 Kpa; varied air and water flow;: calculated relative permeability of air and water with eqn 3 and eqn 4. (Figure 4, 5, 6)

•0.4M KBr tracer loaded in coiled tube, spliced to main water line. Water directed through coil for test. Effluent emptied into a fraction collector (Figure 7)

CONCLUSIONS

•X-curve is a valid model for highly fractured cement

•Corey-curve and Brooks-Corey curve are valid models for smaller aperture cement fracture at lower saturation

•>90% water saturation phase interference of water permeability is reduced and water can permeate as if not being acted on by the gas phase

•more water can be transmitted under higher water saturation conditions than predicted by the Corey-curve

•In cement 0.2mm fracture aperture may be an important aperture between the utility of these two models.

•<90% sat water followed Corey-curve and was displaced to smaller aperture regions, resulting in preferential flow and less hydrodynamic dispersion

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