INTEGRATION OF PORE AND CORE SCALE DATA FOR SIMULATION

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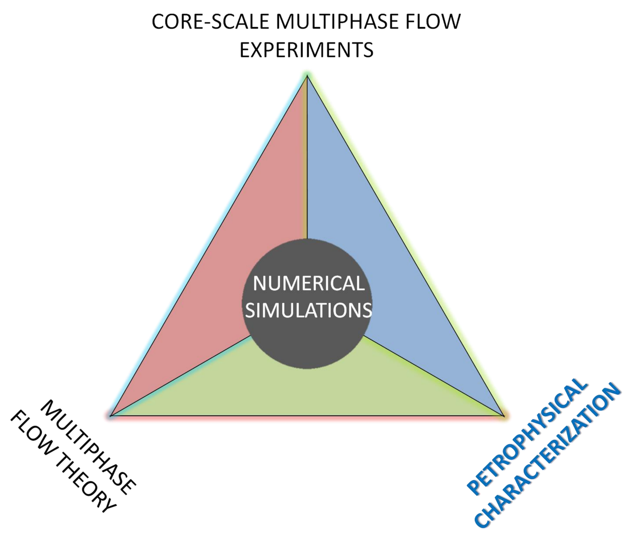
PORE SCALE ANALYSIS

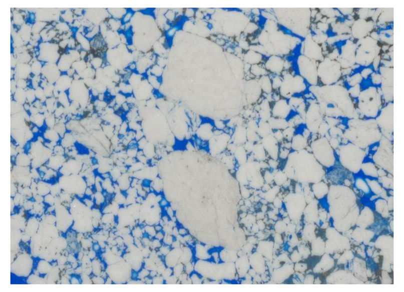
A great deal of effort has gone into understanding the physics of multiphase flow and into representing this behavior at the reservoir scale for hydrocarbon recovery, CO_2 sequestration and a wide range of other applications. Despite the well documented theoretical developments of various phenomena, we are still fundamentally unable to reproduce a simple laboratory experiment in which CO_2 is injected into a brine saturated core under controlled pressure, temperature and composition. The sequestration lab seeks to tackle these issues by taking a multi-disciplinary approach.



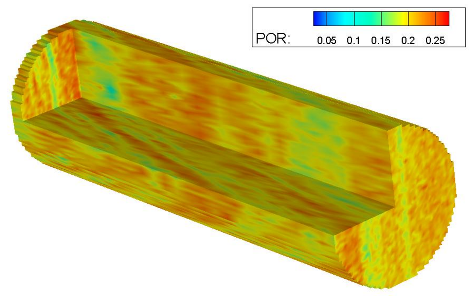
THE SEQUESTRATION LAB

The goal of the Sequestration Lab is to develop the ability to predict the spatial and temporal distribution of CO_2 saturation and trapping through an improved understanding of the pore and core scale physics over the life cycle of a sequestration project.

How Does My Work Fit In



One of the most important parts of testing the physics is bridging the gap between scales. The goal of this work is to study the integration of pore scale features into core scale models, particularly the development of a method by which to calculate permeability from porosity data.



THEORETICAL DEVELOPMENT

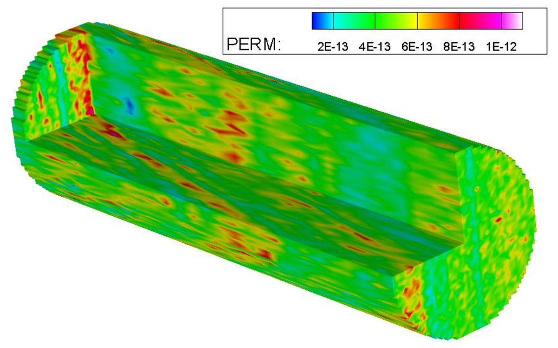
Porosity data comes from using a CT device to scan the core, from this porosity data we must derive the remaining geological input data for simulation

Carman-Kozeny Equation – Equation 1

$$k = \frac{\phi^3}{S(1-\phi)^2}$$

S is a core scale empirical constant

PERMEABILITY – EQUATION 1



Leverett's J-Function

$$P_{c,i} = \sqrt{\frac{\phi_i}{k_i}} \cdot J(S_w)$$

P_c is a Function of ϕ and k

Include pore scale information relating S to porosity to improve the relationship

Carman-Kozeny uses hydraulic radius to derive its form, the equation includes a variable called specific surface area, or the amount of surface area per unit volume.

$$k = \frac{\phi^3}{2\tau \cdot a_v^2 \cdot (1-\phi)^2}$$

τ – Tortuosity

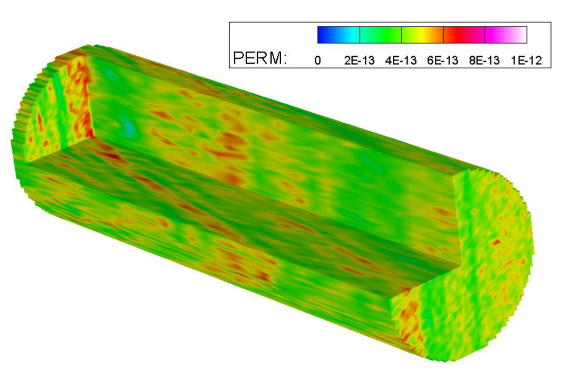
a_v – Specific Surface Area

Measure a_v in a 2-D Rock Section and Relate to Porosity

We can use a thin section to measure a_v and porosity and develop a relationship between a_v and ϕ, using regression analysis. The resulting relationship can then be substituted into the original equation. Since a thin section is a 2-D representation, a_v is not specific surface area, but specific perimeter, or the perimeter per unit area.

$$k = \frac{S}{(\mathcal{F}(\phi))^2} \frac{\phi^3}{(1-\phi)^2} \qquad a_v = \frac{\sum \text{Perimeter}}{\text{Measured Area}}$$

PERMEABILITY – EQUATION 2



New Carman-Kozeny Equation – Equation 2

$$k = \frac{S}{(0.3283\phi^{0.77})^2} \frac{\phi^3}{(1-\phi)^2}$$

THIN SECTION ANALYSIS AND SIMULATION RESULTS

Plots of specific perimeter vs. porosity for three sandstone thin sections

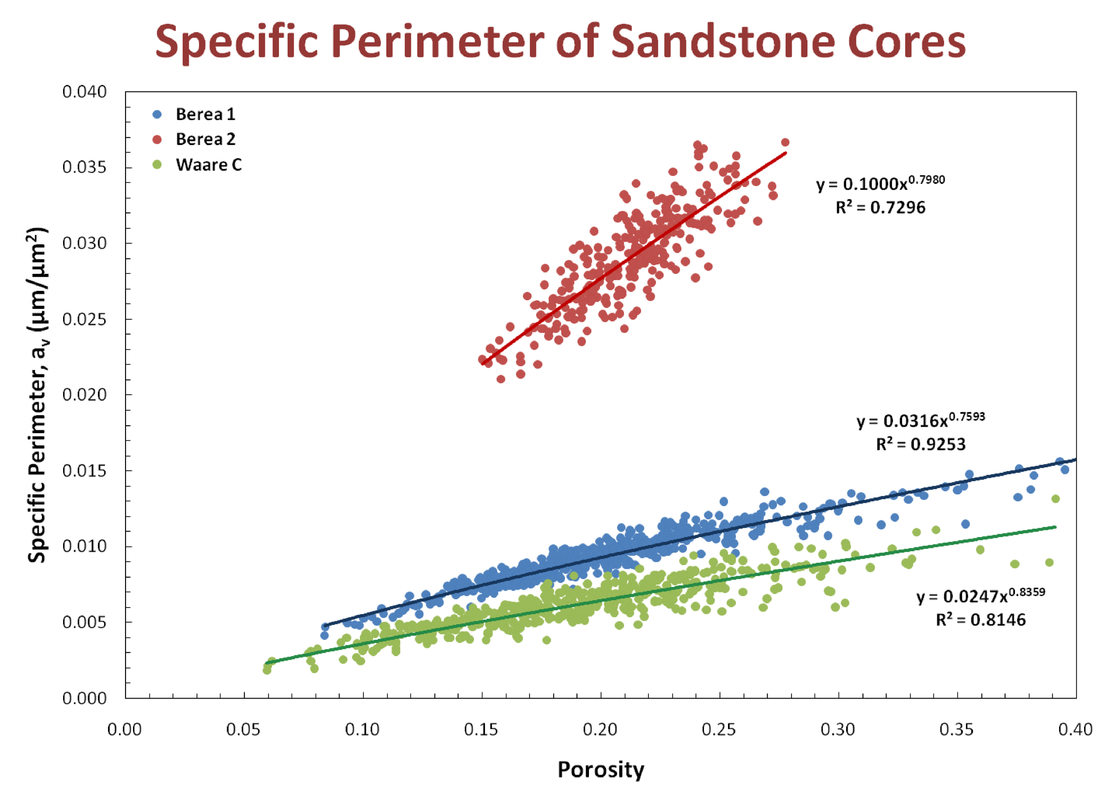
COMMENTS

All samples have qualitatively similar relationships over the expected porosity range

Berea Sandstone 1 is the core used in the simulations

Berea Sandstone 2 is more homogeneous than 1 but has weaker relationship between specific perimeter and porosity

The smaller the sample area in the thin section, the more data points in the plot, but the more error is introduced due to boundary effects



Core saturation at steady state for 50 percent CO_2 injection

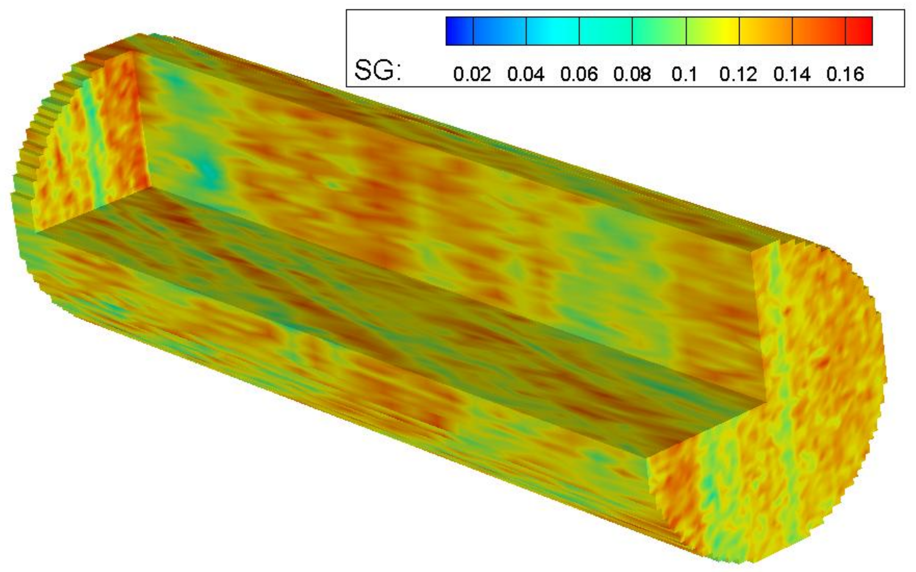
COMMENTS

Changes in saturation distribution are observed, but still does not match experimental results

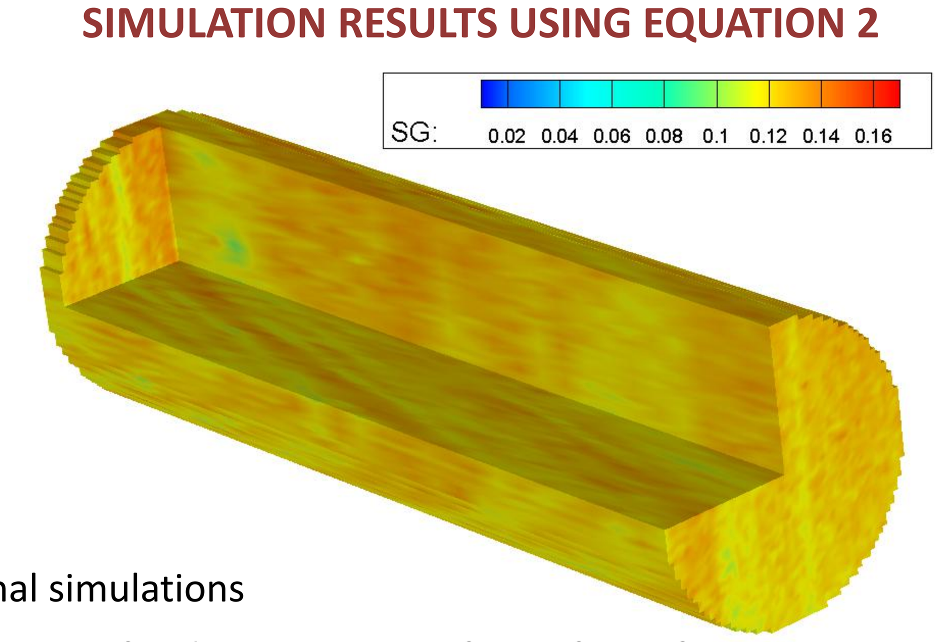
Applying a single relationship for the specific perimeter as in Equation 2, results in less spatial contrast in saturation

Structural features in the core are not accounted for in any special way, but have an obvious effect

SIMULATION RESULTS USING EQUATION 1



SIMULATION RESULTS USING EQUATION 2



FUTURE WORK

Test more thin sections and conduct additional simulations

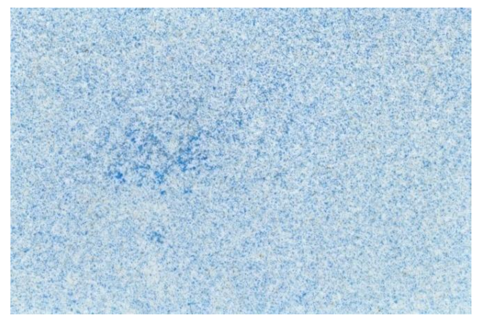
Determine some easily measurable way to account for the 3-D nature of specific surface area

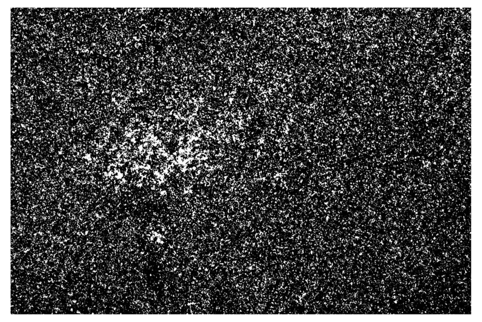
Use thin sections which include structural features from a core to measure differences in the structure of the porosity

PORE SCALE MEASUREMENT

Use Matlab to Analyze Thin Sections

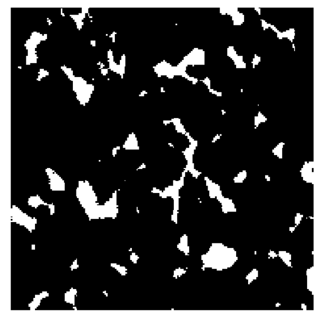
Scan thin section and convert to a binary image

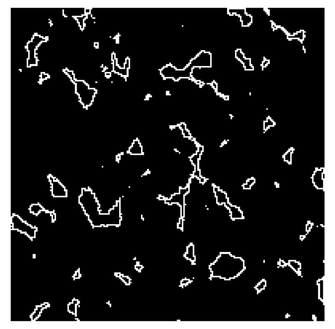




Sum all pore perimeters in a sample area from the image

Sum the area of pore space





For each Sample:

ϕ – 10.02%

a_v – 0.005294 μm/μm²

k – 111.48 md

CONCLUSIONS

MORE PERMEABILITY CONTRAST IS REQUIRED

In order to create a closer match between the model and the experiment, more permeability contrast is required, which will create more contrast in capillary pressure values in the core.

APPLYING A SINGLE RELATIONSHIP IS INSUFFICIENT

Measuring all pores and determining a single relationship for all porosity does not provide the range of permeability required to accurately replicate the experiment

POROSITY SHOULD BE MEASURED BY TYPE

We need a way to apply different relationships for different types of porosity, based solely on the range of porosity values encountered. The presence of clays, silts, and other particles has a strong influence, but bulk porosity is the only parameter we can measure.

ADDITIONAL THIN SECTIONS NEED TO BE EVALUATED

In order to create different relationships for porosity types based solely on bulk porosity measured in CT, thin sections should be obtained from areas with known differences in porosity properties

MEASURING P_C VARIATIONS DIRECTLY BYPASSES LEVERETT'S FUNCTION

If a method could be developed for measuring capillary pressure in a core at the same scale as the saturation is measured in an experiment, this would eliminate error caused by calculating P_c using Leverett's J Function.

ACKNOWLEDGEMENTS

Thank you to GCEP for funding this work, to Sally Benson for absolutely everything she has done, and to Jean-Christophe Perrin, Chia-Wei Kuo, Ljuba Miljikovic, Ethan Chabora and Cindy Ross for just about everything else.

GCEP 4th Annual Energy Symposium Oct 1-3, 2008

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