



Hydrology Days 2012
2012 conference on Earth and Energy Research

Material Characterization for Intermediate-scale Testing to Develop Strategies for Geologic Sequestration of CO₂

HIROKO MORI¹, TOSHIHIRO SAKAKI^{2,3}, TISSA H. ILLANGASEKARE²

¹Dep. of Hydrologic Science and Engineering, Colorado School of Mines, Golden, Colorado, USA ; hmori@mines.edu

²Center for Experimental Study of Subsurface Environmental Processes, Civil and Environmental Engineering, Colorado School of Mines, Golden, Colorado, USA

³International Projects and Services, Nationale Genossenschaft für die Lagerung radioaktiver Abfälle, Wettingen, Switzerland



Center for Experimental Study of Subsurface Environmental Processes

http://cesep.mines.edu

ABSTRACT

In order to develop effective strategies for safely storing CO₂ in deep geological formations, it is necessary to understand the fundamental processes that contribute to stable entrapment in naturally heterogeneous subsurface formations. Because controlled experiments to generate data at all scales of interest are not feasible to perform in field settings, the use of intermediate scale laboratory test systems was pursued to generate comprehensive data sets. Due to the nature of the CO₂ geological sequestration where supercritical CO₂ is injected under high pressure of > 8 MPa, one of the challenges in conducting such experiments under “ambient laboratory conditions” is the selection of test fluids that can be used as surrogates for supercritical CO₂. In this study, a mixture of Glycerol-water (8:2 by weight) and Soltrol 220 was selected as the surrogate fluids for the brine and supercritical CO₂, respectively, based on the fluid properties such as density and viscosity. The study focuses on the methodology to identify the capillary pressure – saturation relationships and the relative permeability of the test sands for the above-mentioned fluids. A 50 cm tall column equipped with a couple of capacitance sensors for phase saturation measurement was used to measure the retention curves. The experimental data were compared with the retention curves obtained using scaling factors obtained from 1) entry pressure and 2) interfacial tension (Leverett scaling). The experimental residual saturations was matched with the retention curve obtained from scaling factor, however, the scaling factor shifts the retention curve vertically, so the residual saturation cannot be determined by these factors. Another series of tests are underway using a long column to measure the relative permeability. These hydraulic properties will be used as the fundamental material properties when simulating the intermediate tank experiments.

1. BACKGROUND & OBJECTIVES

- For geological carbon sequestration, it is essential to understand the capillary trapping of CO₂ in the sand.
- In order to simulate the intermediate tank experiments, the fundamental material properties are crucial.
- For the surrogate fluids, methods for characterizing material properties are not well established.
- Examine measurement methods and characterize hydraulic properties

2. TASKS

Capillary Pressure – Saturation Measurement

- Task 1: Measure entry pressure of Soltrol 220 into the glycerol-water mixture saturated sands and calculate “scaling factor”.
- Task 2: Measure interfacial tension between Soltrol 220 and Glycerol water mixture and calculate “scaling factor”.
- Task 3: Measure retention curves and compare with the scaled data.
- Task 4: From the gained data, obtain the van Genuchten parameters.

Relative Permeability Measurement

- Task 5: Measure the relative permeability of Soltrol 220 and Glycerol water mixture by using long column method.

3. Capillary Pressure – Saturation Measurement

Task 1: Entry pressure measurement

1. Prepare 3 columns of glycerol-water saturated soil (15cm high). Bottom is connected to a constant-head reservoir.
2. Soltrol 220 was slowly injected on the surface of glycerol-water mixture-saturated sand in increments of ~0.5cm.
3. Height of Soltrol 220 was recorded when glycerol-water started to drain from the bottom.
4. Entry pressure head for air-water system for the same sand is compared with the entry pressure head for glycerol water mixture and Soltrol 220 system and gain the scaling factor for the fluid.



ρ_w : density of water 1.0 g/cm³
 ρ_{Soltrol} : density of Soltrol 0.794 g/cm³.
g: gravity 9.81 m/s².

$$\text{Scaling factor} = \frac{\rho_w h_w g}{\rho_{\text{Soltrol}} h_{\text{Soltrol}} g} \quad \text{scaling factor} = 0.27-0.38$$

Task 2: Interfacial tension measurement

Leverett Scaling relates P_c for different interfacial tensions for the same sand matrix.

$$\frac{P_{c1} \left(\frac{k_1}{\phi_1} \right)^{1/2}}{\sigma_1} = \frac{P_{c2} \left(\frac{k_2}{\phi_2} \right)^{1/2}}{\sigma_2}$$

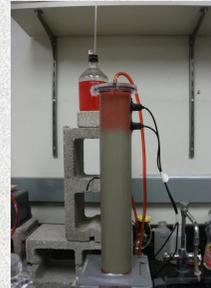
P_c : capillary pressure [kPa]
 σ : interfacial tension [dyne/cm]
K: hydraulic conductivity [cm/s]
 ϕ : porosity [-]

Interfacial Tension [dyne/cm]	
Water and Air	73
Glycerol-water and Soltrol220	17.3

$$\text{scaling factor} = 0.24$$

Task 3: Retention curve

1. Fill the column with glycerol-water saturated sand
2. Phase saturations at two depths (5 and 10 cm from the top) in the column were measured using EC-5 sensors. Sensors were calibrated in advance.
3. Glycerol-water pressure was slowly decreased by lowering the constant-head reservoir connected to the bottom.
4. Mass outflow of Glycerol-water mixture and Soltrol 220 were monitored.
5. The retention curves in drainage and wetting cycles were measured.



Task 4: van Genuchten parameters

The van Genuchten parameters α , m and n were fitted by using obtained retention curve data. Van Genuchten model (1980).

$$\text{Saturation} = \left(1 + (\alpha \times \text{capillary pressure})^n \right)^{-\left(1 - \frac{1}{n}\right)}$$

4. Relative Permeability Measurement

Task 5: Long column method

1. Saturate sand with glycerol-water mixture.
2. Start injecting Glycerol –water mixture and Soltrol 220 from the top by using needles adjust the inflow and outflow of the column.
3. Start draining the fluid from constant-head reservoir.
4. Wait until the sensors and tensiometers get stable.
5. Measure the head difference, mass outflow and time then calculate the hydraulic conductivity by using Darcy's law.



$$k_r = K/K_{\text{sat}}$$

k_r : relative permeability [-]

K: the hydraulic conductivity which measured by column [cm/s]

K_{sat} : hydraulic conductivity for one phase measurement. [cm/s]

The saturated hydraulic conductivity of Soltrol 220 and Glycerol water mixture is calculated by using following equation.

$$K = \frac{k \rho g}{\mu}$$

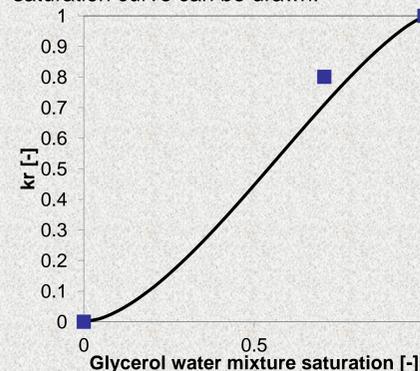
K: Hydraulic conductivity [cm/s]
k: intrinsic permeability [cm²]
 ρ : density [g/cm³]
g: gravity 9.81 m/s²
 μ : viscosity [Pa s]

Intrinsic permeability is porous media dependent so it can be calculated the air water hydraulic conductivity measurement for same sand.

5. RESULTS

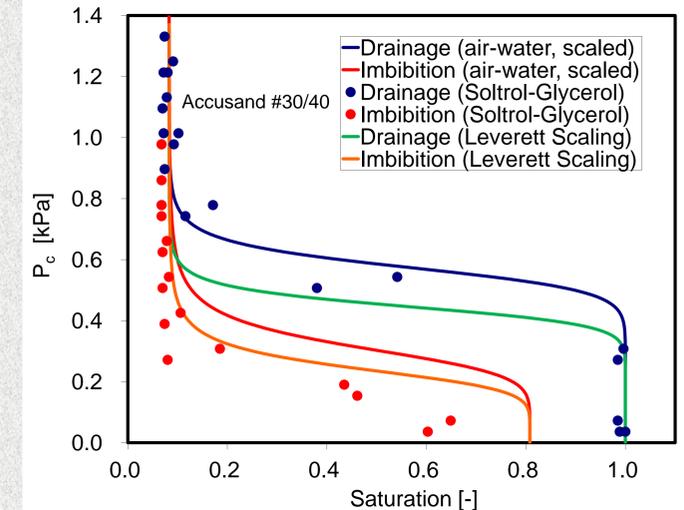
Relative permeability

By applying the van Genuchten parameters to Mualem model the k_r -saturation curve can be drawn.



•From this measurement, there are difference between the Mualem model and experimental data.
•In order to determine that the measured data is correct, we need to develop another method to measure the relative permeability and compare the result.

Capillary pressure – Saturation curves



Van Genuchte parameters					
Accusand		Residual Water Content [-]	Maximum Water Content [-]	α	n
#30_40	drain	0.028	0.334	0.21	6.77
	imbibition	0.028	0.242	0.590	4.906

- Despite slight differences between the scaled air-water retention curves based on two scaling factors, they show reasonable match with the measured data.
- The scaling factor shifts the retention curve vertically, so residual saturation cannot be determined by these factors.

CONCLUSION

•From capillary pressure measurement, we showed that Leverett scaling can be apply for retention curve measurement by measuring; 1) entry pressure or 2) interfacial tension of two fluids.

FUTURE WORK

- Develop another method to measure the relative permeability and compare the results.

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ACKNOWLEDGEMENT

This research was partially supported by JASSO, DOE, and NSF. I am really thankful for all those who helped me with my research.