Characterization of two-phase flow in porous media and applications to the monitoring of geological carbon sequestration

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Characterization of Two-Phase Flow in Porous Media and Applications to the Monitoring of Geological Carbon Sequestration

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- **Project duration**: 3 years
- **Supervisor**: Dr. Diganta Das, Prof. C.D. Rielly
- **Main research question**: What are the implications of non-uniqueness in the characterization parameters of two-phase flow systems in the porous media?
- **Relevance for implementation of CCS**: Non uniqueness in the characterization parameters of a system affect their applications in the modeling of such system. For CO_2-water system, such scenario affects the monitoring and control of the system. This work determines and quantifies the presence of dynamic effects in the characterization parameters of CO_2-water system. Results are vital to effective monitoring of CO_2 migration in the subsurface.
- **Results**: Dynamic coefficient and geoelectrical characterization of the CO_2-water system in porous media.

Introduction

- The issue of global warming and the proposed geological carbon sequestration have increased the interests on studying supercritical CO_2 ($scCO_2$) and brine/water flow in porous medium.
- Like other two-phase flow systems in porous media, the capillary pressure (P^c), relative permeability (K_r) and electrical properties (e.g., bulk electrical conductivity (σ_b), bulk dielectric constant (ε_b)) of the fluid-fluid-porous media systems can be used as the characterization functions as they are all functions of wetting-phase saturation (S) (Plug et al. 2007).
- But the non uniqueness of these functions pose challenges to efficient and reliable monitoring of the subsurface processes.
- Furthermore, as CO_2 migrates to different positions in the aquifer where it is injected , it is desirable to investigate the behaviours at different stages of the migration using combined characterization techniques.

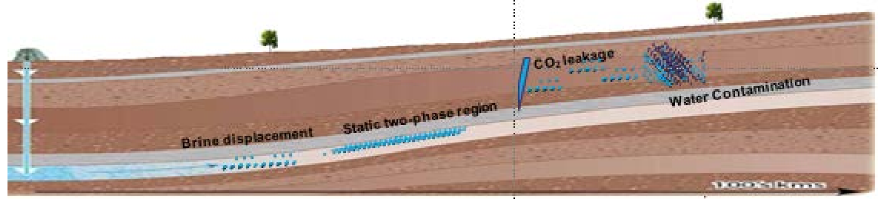


Figure 1: Illustration of the multistage migration of CO_2 in the aquifer

Research questions

- Do dynamic effects exist in the characterization parameters of supercritical CO_2-brine/water system in the subsurface?
- If yes, what are the implications in the studying and monitoring of the system?
- How can we possibly study and monitor multistage migration of CO_2-brine/water in the subsurface?

Methods

- Figure 2 shows the experimental set up. CO_2 was injected into the domain , previously saturated with brine/water and the pressures of the phase were measured by pressure transducers.
- The faces of the sensors were distinguished with PTFE membrane for non-wetting phase (CO_2) pressure measurement while the nylon membrane was used for brine/water phase pressure measurement.
- Water saturation was measured using time domain reflectomtery (TDR) technique. TDR probes (Campbell Scientific, UK) are shown in Fig. 3C as a wave guide for the impulses generated by the reflectometer (TDR100).
- While the pressure sensors and the TDR gave us the readings for the P^c-S measurements, the TDR further gave us the readings for the ε_b-S and σ_b-S relationships. Furthermore, silicone rubber, as a selectively-permeable membrane also gave us indication of CO_2 at various conditions.
- For the **dynamic drainage**, constant pressure was set on the supercritical fluid pump (Teledyne Isco, Lincoln, USA)
- The **equilibrium or quasi static experiments** were conducted by using single-pump gradient program of the supercritical fluid pump. At gradient program mode the pump was raised at 0.5 kPa every hour.
- To investigate leakage of the CO_2, experiments were designed to mimic the presence of CO_2 at different depths of the subsurface . Different conditions of temperature and pressure were assigned to different depths following the standards recommended by Best (2013) and (Nordbotten et al. 2004).

Investigations were conducted in the silicate and carbonate porous media. Also, the permeation of CO_2 and N_2 under different conditions were investigated using silicone rubber.
Simple criterion was developed to distiguinsh the presence of the different gases.

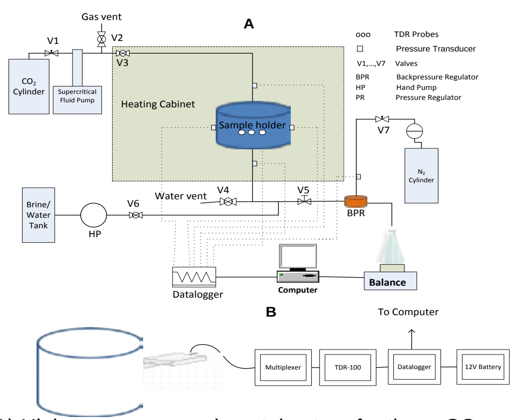


Figure 2: (A) High-pressure experimental set-up for the $scCO_2$-brine/water system (B) Schematics of TDR measurement system.

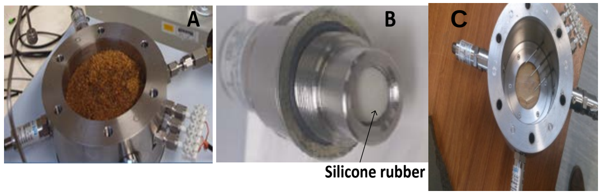
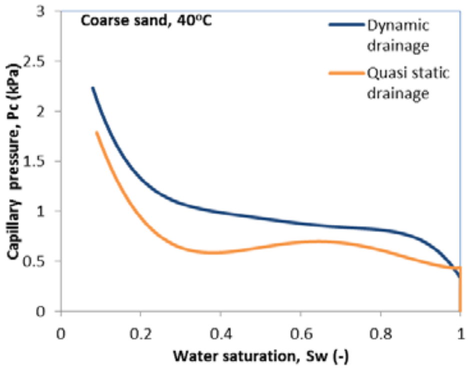


Figure 3: Photographs showing (A) the sample holder with silica sand and sensors (B) Sensor and holder with the silicone rubber (indicated with arrow) (C) sample holder with the TDR probes showing insulated part (Cell internal diameter: 10cm, sample height: 4cm)

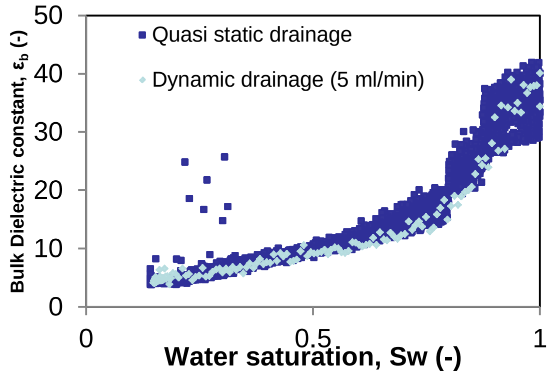
Results

Dynamic effects

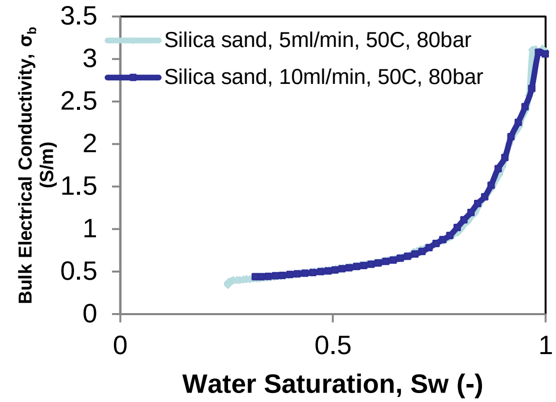
P^C-S



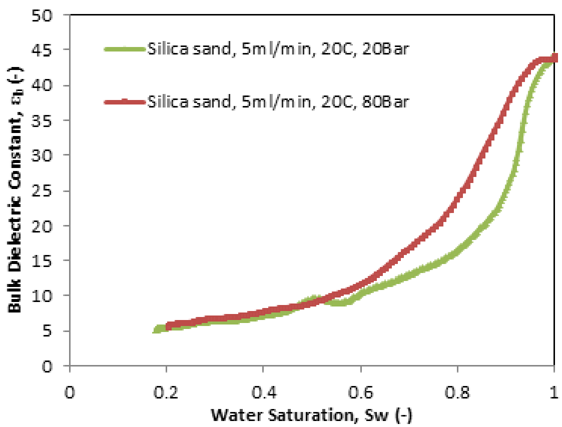
Dielectric Constant



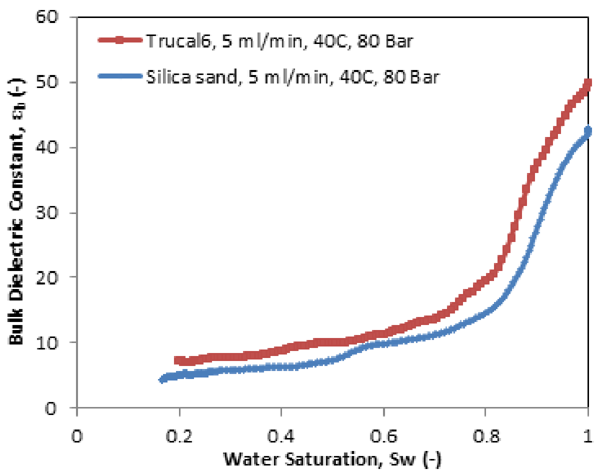
Electrical conductivity



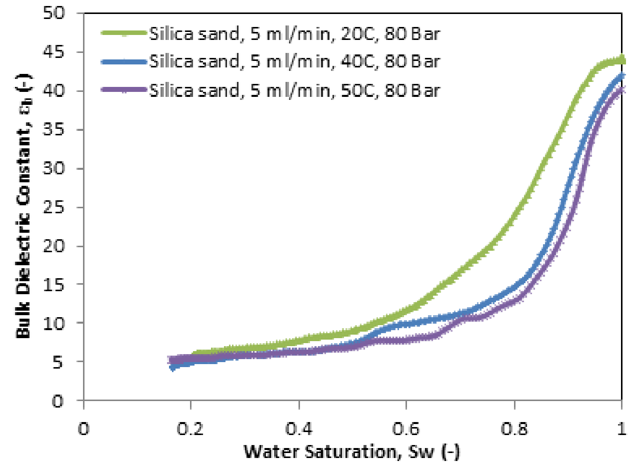
Effects of pressure



Effects of porous media type



Effects of temperature



Discussions and Conclusion

- Dynamic effect is present in the P^c-S relationships for supercritical CO_2-brine/water. However, there are no significant dynamic effects in the σ_b-S and ε_b-S relationships. This implies that the application of P^c-S relationships in the investigation of supercritical CO_2-brine/water must make use of the modified relation for dynamic and equilibrium (Kalaydjian (1992) and Hassanizadeh and Gray (1993)): $P^{c,dyn} - P^{c,static} = -\tau\left(\frac{\partial S}{\partial t}\right)$

- The injection depths of the CO_2 will determine the behaviours of the ε_b-S relationships. This is because the relationship was found to change with pressure and temperature. ε_b-S curve rises as the pressure increases. This is attributed to the likely increase in the amount of bound water as the pressure increases. Also, the ε_b-S curve decreases as the temperature increases in silica sand while the reverse is the case in the limestone.

- Media sample type affects the ε_b-S and σ_b-S relationships. Under similar conditions, they are higher for supercritical CO_2-brine/water in limestone than silica sand.

- Permeability of the silicone rubber to different gases seems unaffected by the different condition of the system. At different temperature and pressure of the CO_2 (corresponding to different depth), the permeability curves remain similar (see Figure in page 7).

- Simple criterion for the detection of the permeating gas into the membrane can be achieved with the use of the mass gradient of the permeating gas (see Figure in page 8)

Acknowledgement

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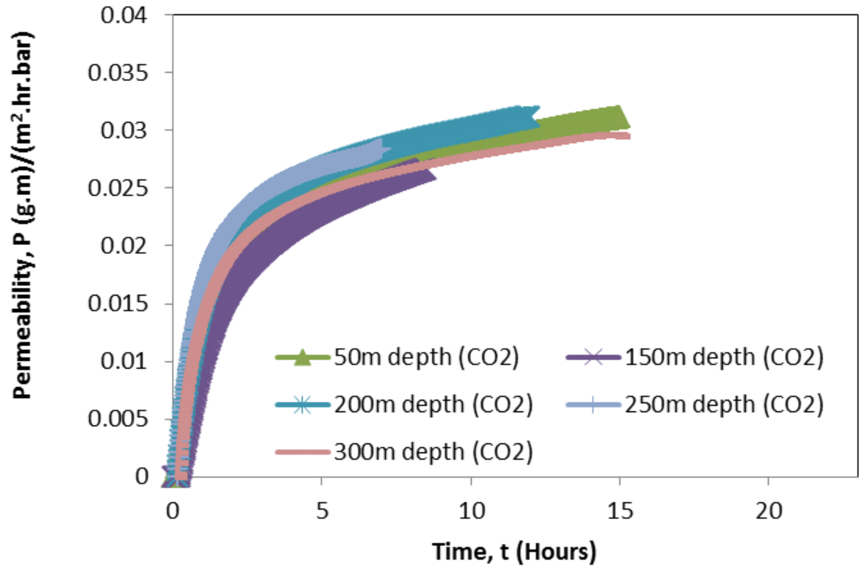
Permeability of the silicone rubber membrane under different conditions



Slope of the mass permeation rate curve against depth for different gases