DYNAMIC EFFECT IN CAPILLARY PRESSURE-SATURATION RELATIONSHIP FOR CO$_2$-H$_2$O-SAND SYSTEM: APPLICATION TO CO$_2$ SEQUESTRATION

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INTRODUCTION

- Aquifers and reservoirs are primarily hosts to water and brine.

- Being water-wet, displacement pressure is required to overcome the capillary forces in order for oil or other non-wetting fluids to replace the original water/brine.

- The capillary pressure curve describes the pressure required to displace from the rock a wetting fluid at initially 100% saturation to a given saturation.
Capillary pressure is a direct measurement of wettability (Anderson, 1987) and is employed in:

- determining reservoir initial fluid saturations and its variations across a reservoir.
- cap rock seal integrity.
- and as ancillary data in the assessment of relative permeability data.
- To find optimal well path in reservoirs of different or folded sand layers.
Traditional multiphase capillary equation

\[ P_{nw} - P_w = P^c(S_w) \]  \hspace{1cm} (1)

CHALLENGES

- Assumes validity under all conditions
- Assumes the capillary pressure to be a function of the wetting phase saturation only
- Inability to describe dynamic portion of flow
- Non-uniqueness of capillary pressure for drainage and imbibition
MODIFICATION TO CAPILLARY PRESSURE RELATION

\[ p_{c,dyn} - p_{c,equ} = -\tau \frac{\partial \sigma}{\partial t} \]  


Characteristics

- Accounts for dynamic portion of the flow
- \( \tau \) is fluid and material property (Joekar-Niasah and Hassanizadeh, 2011).
- It is an indication of how close or far the system is to equilibrium (Das et al., 2007).
- \( \tau \) may be related to phase trapping, capillary blockage (and consequently interfacial area) and contact angle (Hassanizadeh et al., 2002)
**PREVIOUS WORKS ON $t$**

- Paraffin oil-water system (Tsakiroglou *et al.*, 2006)
- Silicon oil-water-sand system (Mirzaei and Das, 2007)
- PCE-water-sand system (Das *et al.*, 2007; Bottero 2009)
- Multistep flow experiments (O’Caroll *et al.*, 2005)
- Influence of wettability (O’Caroll *et al.*, 2010)
- Grain size dependency and (Camps-Roach *et al.*, 2010)
- Upscaling.
- Impacts on Unsaturated flow: (Hassanizadeh *et al.*, 2002)
  vadoze zone.
- Dynamic Pore network model (Joekar-Niasar and
  Hassanizadeh, 2010)
- Darcy-Scale models (Das *et al.*, 2005; Manthey *et
  al.*, 2005)
- Pore-scale models (Dahle *et al.*, 2005; Gielen *et
  al.*, 2005)
Preliminary experiments utilised silicone oil of the following viscosities with scales:

- Viscosities: 200, 500 and 1000 cSt
- Scales: 4, 8 and 12 cm.
CAPILLARY-PRESSURE PROFILE

![Graph showing capillary pressure profile](image)
DYNAMIC COEFFICIENTS AT DIFFERENT SCALES AND VISCOSITIES

- 4 cm 200 cSt
- 4 cm 500 cSt
- 4 cm 1000 cSt

Dynamic Coefficient, $\tau (\text{Pa}s)$

Water Saturation, $S_w (-)$
4, 8 and 12 cm – 200 cSt
200, 500 and 1000 cSt – 12cm (Whole)
Software

- Subsurface Transport over Multiple Phases (STOMP) (PNNL, USA).

Material Properties (Permeability)

- Fine Sand \( (5.66 \times 10^{-11} \text{ m}^2) \)
- Coarse Sand \( (3.65 \times 10^{-10} \text{ m}^2) \)
- Mixed Sand \( (5.95 \times 10^{-11} \text{ m}^2) \)
EFFECTS OF MATERIAL PROPERTY ON $P_c - S_w$ RELATION @35
EFFECTS OF MATERIAL PROPERTIES ON DYNAMIC EFFECTS

![Graph showing the relationship between dynamic coefficient and water saturation for different materials.

- Fine sand
- Coarse sand
- 50:50 sand

Dynamic Coefficient, $\tau \ (\text{Pa}s)$

Water Saturation, $S_w \ (-)$

0.0 0.2 0.4 0.6 0.8 1.0

0 2 4 6 8 10 12]
Similar Findings

- Effects of Upscaling: Bottero et al., (2011 a, b)
- Effects of Viscosity: Goel and O’Carroll (2011)
- Effects of Temperature: Hanspal and Das (2010)

Previous $P_c - S_w$ Works on CO$_2$- Water System:

- Pentland et al. (2011): End Capillary pressure and Irreducible saturation as well as capillary trapping.
WHAT IS NEW?

- $P_c - S_w$ relationship for CO$_2$-water/brine under quasi static and dynamic drainage and imbibition.

- Investigation of the relationship in different porous media; fine and coarse sands.

- Determination of the dynamic effects and coefficients for above systems.
PROPOSED EXPERIMENTAL SETUP
IN-SITU PRESSURE MEASUREMENT
THANK YOU FOR LISTENING