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

BY

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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

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

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

\[ P_{c,dyn} - P_{c,eq} = -\tau \frac{\partial S}{\partial t} \]  

(2)


**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 $\tau$

- 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 upscaling (Camps-Roach et al., 2010)
- Impacts on Unsaturated flow: vadose zone (Hassanizadeh et al., 2002)
- 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 vs water saturation]
DYNAMIC COEFFICIENTS AT DIFFERENT SCALES AND VISCOSITIES

![Graph showing dynamic coefficients at different scales and viscosities.](image)

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

**Y-axis:** Dynamic Coefficient, $\tau$ (Pa.s)

**X-axis:** Water Saturation, $S_w$ (-)

Legend:
- Red crosses: 4 cm 200 cSt
- Green triangles: 4 cm 500 cSt
- Blue circles: 4 cm 1000 cSt
4, 8 and 12 cm – 200 cSt

Dynamic Coefficient, $\tau_{\text{us}}$ vs Water Saturation, $S_w$ (-)
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 effects of water saturation on dynamic coefficient for different materials.](image)

- **Fine sand**
- **Coarse sand**
- **50:50 sand**

- The dynamic coefficient, $\tau (\text{Pa.s})$, decreases as water saturation, $S_w$ (-), increases.

- The graph compares the dynamic effects of different materials under varying water saturation conditions.
EFFECTS OF TEMPERATURE (COARSE)
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.
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