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Additional Information:

- This is a conference presentation.

Metadata Record: https://dspace.lboro.ac.uk/2134/15649

Version: Published

Publisher: UK Carbon Capture and Storage Research Centre (UKCCSRC)

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

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UKCCSC Winter School 2013, University of Edinburgh
January 8-11$^{th}$, 2013
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.
MULTIPHASE THEORY

- 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

\[ p_{c,dyn} - p_{c,equ} = -\tau \frac{\partial S}{\partial t} \]  \hspace{1cm} (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 (Camps-Roach et al., 2010)
  - Upscaling.
- Impacts on Unsaturated flow: (Hassanizadeh et al., 2002)
  - vadose 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

![Diagram showing capillary pressure profile](image-url)

- Capillary pressure, $P_c$ (kPa)
- Water saturation, $S_w$ (-)
- Data points for different conditions:
  - 4 cm Qs 500 cSt
  - 4 cm 10 kPa 500 cSt
  - 4 cm 15 kPa 500 cSt
  - 4 cm 20 kPa 500 cSt
DYNAMIC COEFFICIENTS AT DIFFERENT SCALES AND VISCOSITIES

The graph shows the dynamic coefficient, $\tau$, as a function of water saturation, $S_w$, for different scales and viscosities. The data points are color-coded for clarity:

- Red crosses: 4 cm 200 cSt
- Green triangles: 4 cm 500 cSt
- Blue circles: 4 cm 1000 cSt

The x-axis represents water saturation, $S_w$, ranging from 0.0 to 1.0, while the y-axis represents the dynamic coefficient, $\tau$, ranging from 0.0 to 1.2e+7.
4, 8 and 12 cm – 200 cSt

![Graph showing dynamic coefficient $\tau(\nu_s)$ vs. water saturation $S_w$ for different lengths and viscosities.](image-url)
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, and 50:50 sand. The dynamic coefficient decreases as water saturation increases, with different materials having distinct curves.](image)
EFFECTS OF TEMPERATURE (COARSE)

![Graph showing the dynamic coefficient (τₜₐₘ) versus water saturation (Sₜ) at different temperatures: 35°C, 45°C, 55°C, and 65°C. The graph illustrates a decrease in dynamic coefficient as water saturation increases for all temperatures.]
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