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Wettability-controlled phase transition in displacement- and trapping efficiency in 3D porous media: A micro-CT study

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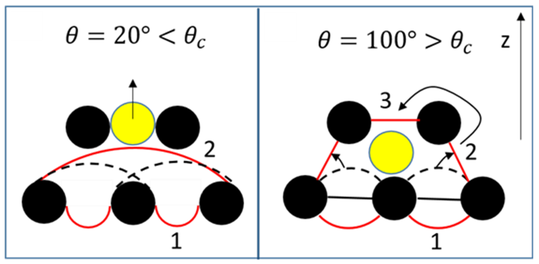
INTRODUCTION:

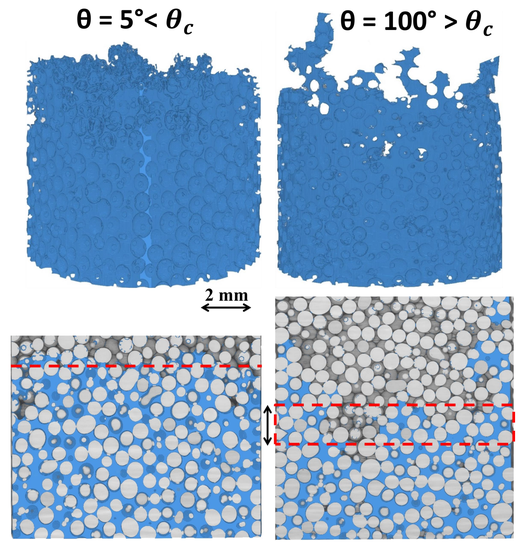
Fluid invasion, displacement of one fluid by another in porous media is important in large number of industrial and natural processes. Of special interest is the trapping of gas & oil clusters. We study the impact of wettability on fluid pattern formation and capillary trapping in glass beads during fluid invasion at Capillary number of 10^{-7} using micro-CT. The contact angle (CA) on glass beads were varied from **5° to 100°** using Piranha cleaning and silanization. A sharp phase transition at $\theta_c = 86°$ was observed. Below θ_c the morphology of the displacement front was ***flat*** and ***compact*** caused by strong smoothing effect of ***cooperative filling***. Above θ_c the morphology of the displacement front was ***fractal*** and ***ramified*** caused by ***single bursts (Haines Jumps).*** Across this dynamical phase transition the trapping efficiency changes from ***no-trapping*** to ***maximal trapping***.

*-- [**Submitted to Water Resources Research**] --*

RESULTS & DISCUSSION:

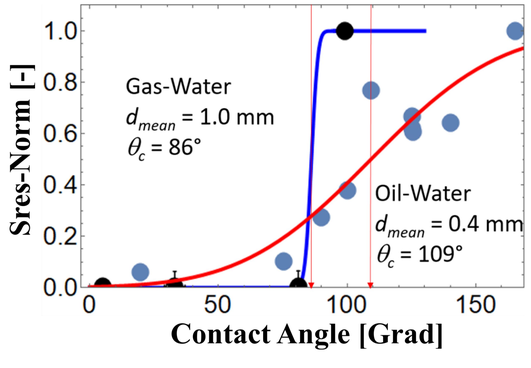
1- Front Morphology:

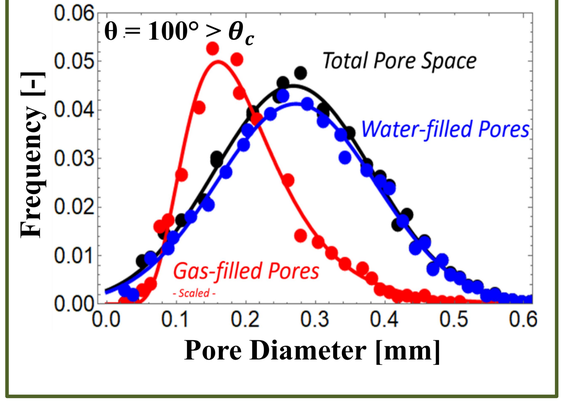




➢ ***NO SMOOTHING EFFECT RESULTS INTO SIGNIFICANT TRAPPING OF DEFENDING FLUID***

2- Capillary Trapping:

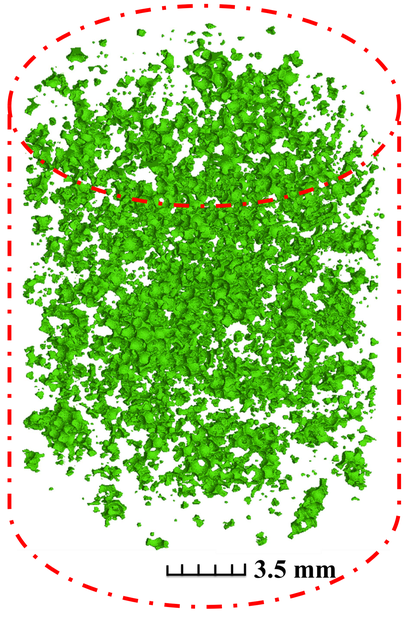


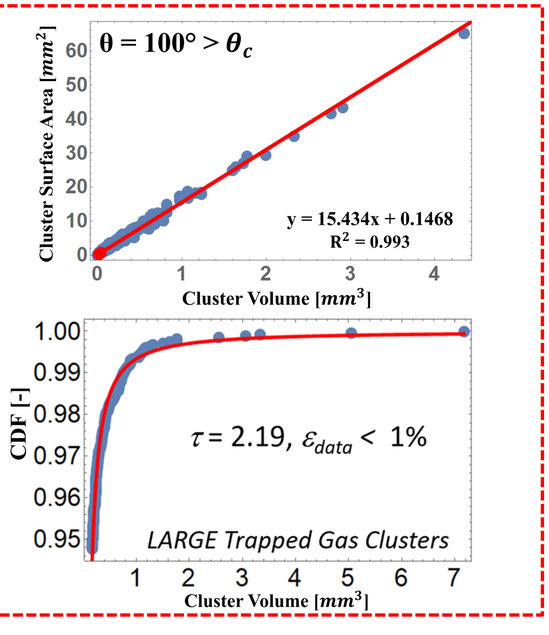


For $\theta > \theta_c$

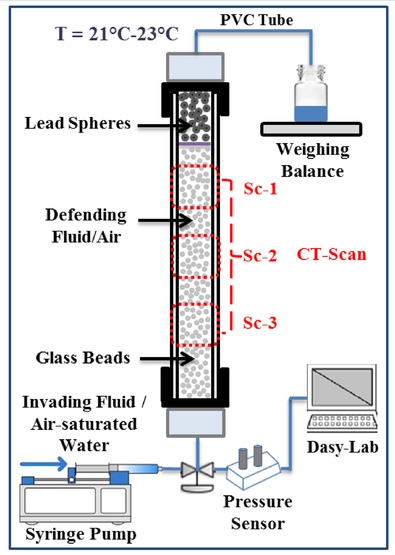
➢ ***Interfacial area is 1.6 times larger for $\theta > \theta_c$ compared to $\theta < \theta_c$***

3- Universal Scaling





MATERIAL & METHODS:



➢ **Sediments:** Glass beads (rough. < 0.02 µm), ***dmean = 0.98*** and ***PSD = 0.273 mm***

➢ **Wettability Alteration:**

- **θ = *5° ± 2°;*** GBS were Piranha ($H_2O_2 : H_2SO_4$ = 1:3) treated & ultrasonically cleaned with de-ionized water
- **θ = *78° ± 3°*, *ϑ = 99° ± 3°***; Deposition of self-assembled monolayer of dichloro-dimethyl silane on GBS

➢ **CA measurement**: *Drop Shape Analyzer 100* (Krüss, Germany) using Analog Glass Plate Method (Herring et al., 2016)

➢ **µ-CT:** *Spatial resolution **0.013 mm***, i.e. Fluid meniscus resolved by ***22*** *voxels along the diameter*

CONCLUSIONS:

➢ **Dynamic Phase Transition** (*Wettability governs the percolation transition*)

- For **θ < θ_c:** Front morphology is ***flat*** and ***compact*** -- ***Cooperative filling*** --
- For **θ > θ_c:** Front morphology is ***fractal*** and ***ramified*** -- ***Haines Jumps*** –

➢ **Cross Over in Trapping Efficiency**

- The transition (***occurs withing 10°***) in the pattern formation causes a cross-over in trapping efficiency by **100 %**, i.e. ***No trapping*** *to* ***maximal trapping*** with gas clusters occupying the ***smaller pores***

➢ **Universal Scaling of Cluster size distribution: Power-law behavior**

- For **θ > θ_c:** Invasion Percolation governs the fluid displacement

REFERENCES:

- Geistlinger et al., **(2015)**. Capillary trapping mechanisms in strongly water-wet systems: Comparison between exp. & percolation theory. ***Adv. in Water Res.,*** 79, 35-50.
- Herring, A et al., **(2016)**. Impact of wettability alteration on 3D nonwetting phase trapping and transport. **Int. J. Greenhouse Gas Contr.,** 46, 175-186.

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