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Micromodel Study on Pore-Scale Mechanisms Associated with Permeability Impairment in Porous media

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BACKGROUND AND MOTIVATION

- ✓ Methane Hydrate bearing sediments are potential energy resource reserving 500-1000Gt of carbon world wide.
- ✓ Dissociation of hydrate into gas and water is the preliminary process in gas production.
- ✓ Mobilization and migration of fines during gas production reduce the permeability of the formation.
- ✓ Laboratory column studies reveal the reduction in permeability during single and two-phase flow.
- ✓ Clogging of pore throats by fines significantly decrease permeability.
- ✓ The fines mobilized by the gas-water interface might impact the permeability.
- ✓ Pore-scale visualization studies need to be conducted to understand the mechanisms responsible for permeability reduction during two-phase flow.

OBJECTIVES

The objective of this study was to investigate the pore-scale mechanisms associated with fines mobilization on permeability reduction during two-phase flow using a micromodel.

EXPERIMENTAL STUDY

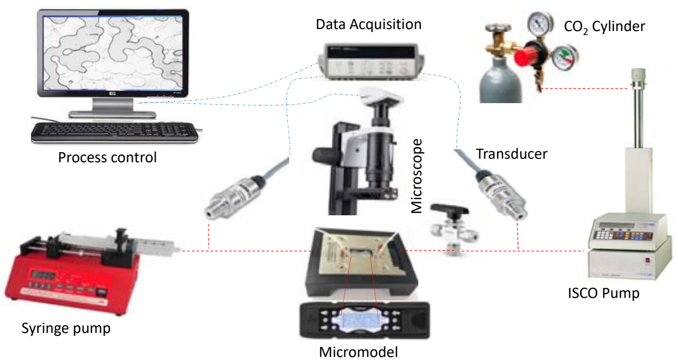


Figure 1: Experimental Set-up

- ✓ **MATERIALS**
  - ✓ Glass Micromodels fabricated by Micronit Microfluidics
  - ✓ Fines: Carboxylate modified Polystyrene latex particles of 5 µm diameter
  - ✓ Fluids: Wetting phase (Brine solution (1 mM of NaCl and pH 4)) and Non-wetting phase (CO_2 gas)
- ✓ **METHODS**
  - ✓ Determination of the following before and after fine injection
  1. Absolute Water permeability
     - Saturate micromodel with water (with or without fines)
     - Measure pressure drop across the micromodel at different flow rates
  2. Effective CO2 permeability
     - Saturate micromodel with water (with or without fines)
     - Inject CO2 at 0.5, 1 & 2 mL/min
     - Measure pressure drop across the micromodel
  3. CO2 breakthrough pressure
     - Measure the pressure drop during CO2 breakthrough in the micromodel
  - ✓ Capture images at various locations

Viscosity of water (cP), μ_w	0.91
Viscosity of CO_2 (cP), μ_{CO2}	0.01473
Area (cm²), A	0.002
Length (cm), L	2

$$K = \frac{\mu L}{A}\frac{Q}{\Delta P}$$

K: Permeability, D
Q: Volumetric Discharge, mL/s
ΔP: Pressure Drop, atm

RESULTS

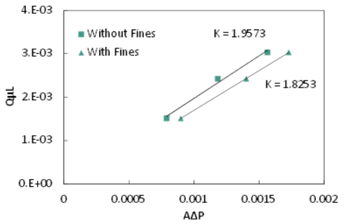


Figure 2: Absolute permeability of micromodel calculated as the slope of volumetric discharge and pressure drop before and after fine injection

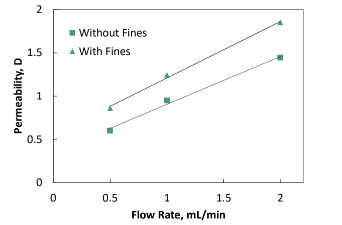
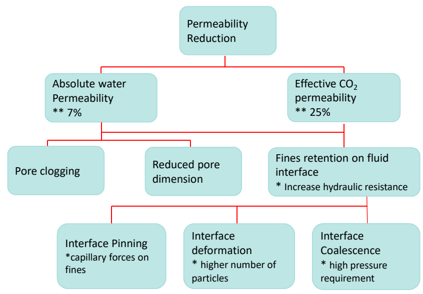


Figure 3: Variation of effective permeability of CO_2 with the flow rate before and after fine injection



- ✓ Breakthrough pressure of CO2 increased 39% with the presence of fines

- ✓ Based on the pore-scale observations, the reduction in permeability is affected by the following factors:
  - ✓ Percentage of particles in the porous media: increased retention on gas-water interfaces
  - ✓ Type of particles (i.e., hydrophilic or hydrophobic): the strength of capillary forces holding the particles on fluid interface increases with decreasing hydrophobicity.
  - ✓ Solution chemistry (i.e., ionic strength, pH etc.): the adhesion forces on solid surfaces are impacted by surface forces

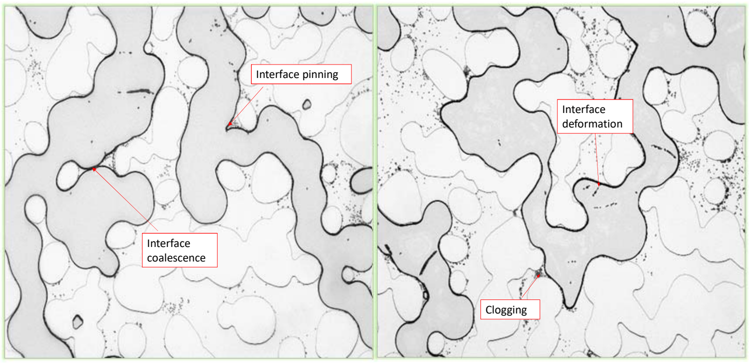


Figure 6: Different mechanisms affecting permeability of the porous media; interface pinning, coalescence and deformation in addition to pore clogging

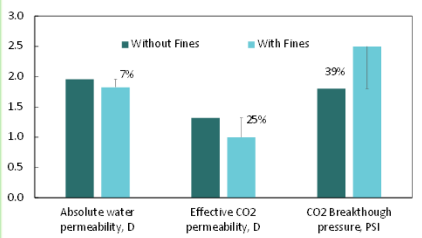


Figure 4: Effect of presence of fines in the micromodel on different factors.

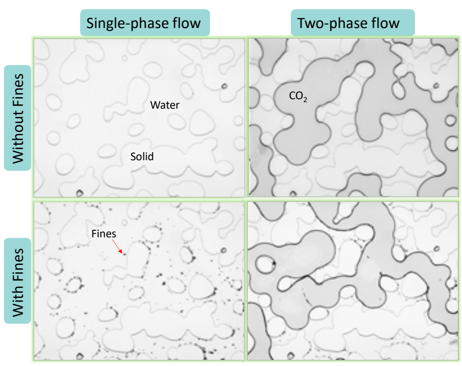


Figure 5: Micromodel images at different permeability measurement conditions

CONCLUSIONS

The important findings from the experimental investigation are summarized below:

- ➢ There is a decrease in permeability of the porous media due to the presence of fine particles.
- ➢ The reduction in permeability during single-phase flow is due to the pore clogging or decreased pore dimensions by the presence of fines.
- ➢ Comparatively higher percentage reduction in effective permeability during two-phase flow with CO_2.
- ➢ The resistance to invade the pores by the gas-water interface increased by the presence of fines in the pore space.
- ➢ Fine particles attached on solid surface are mobilized with the moving gas-water interface and retained on the interface.
- ➢ The capillary retention of fines on gas-water interface pin the interface on grain surface causing higher hydraulic resistance to flow.
- ➢ The coalescence of two moving interfaces require higher capillary pressure due to the presence of fines on the interface.
- ➢ The different pore scale mechanisms (i.e., interface pinning, deformation and coalescence) are responsible for increased reduction in permeability during two-phase flow.
- ➢ The permeability can be affected by the percentage and type of fines and fluid chemistry in the porous medium.

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