Laboratory Investigations for CO_2 Based EOR

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CO2 for EOR as CCUS
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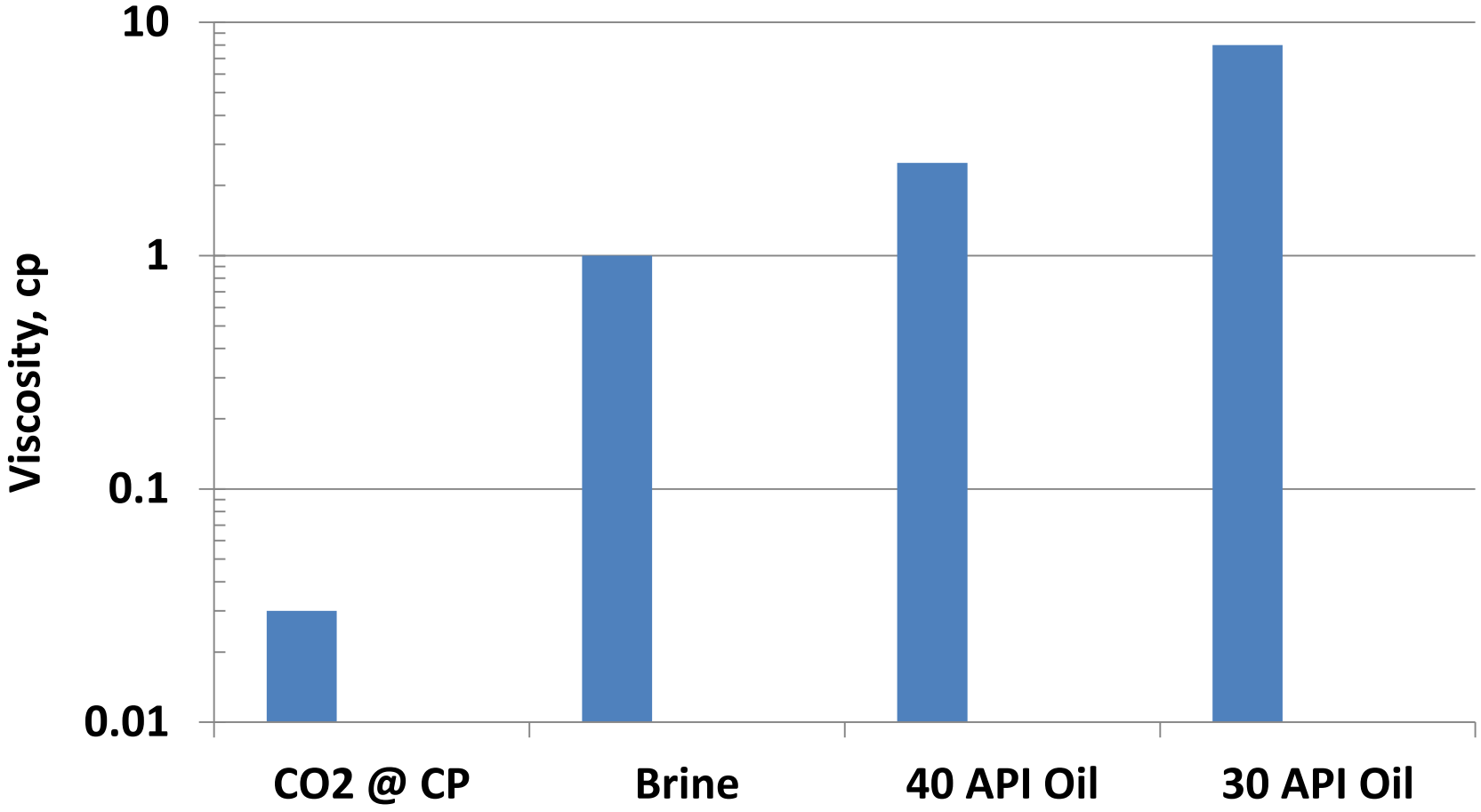
Challenges Facing CO_2 EOR

- Availability of CO_2
- Minimum miscibility pressure (MMP)
- Asphaltene deposition
- Mobility control
  - Low viscosity of CO_2, viscous fingering
  - WAG
  - Gravity segregation
  - Heterogeneities
  - Foam mobility control
- Adsorption

Viscosity of CO_2 and Reservoir Fluids



Displacement Fronts for Different Mobility Ratios and Injected Pore Volumes

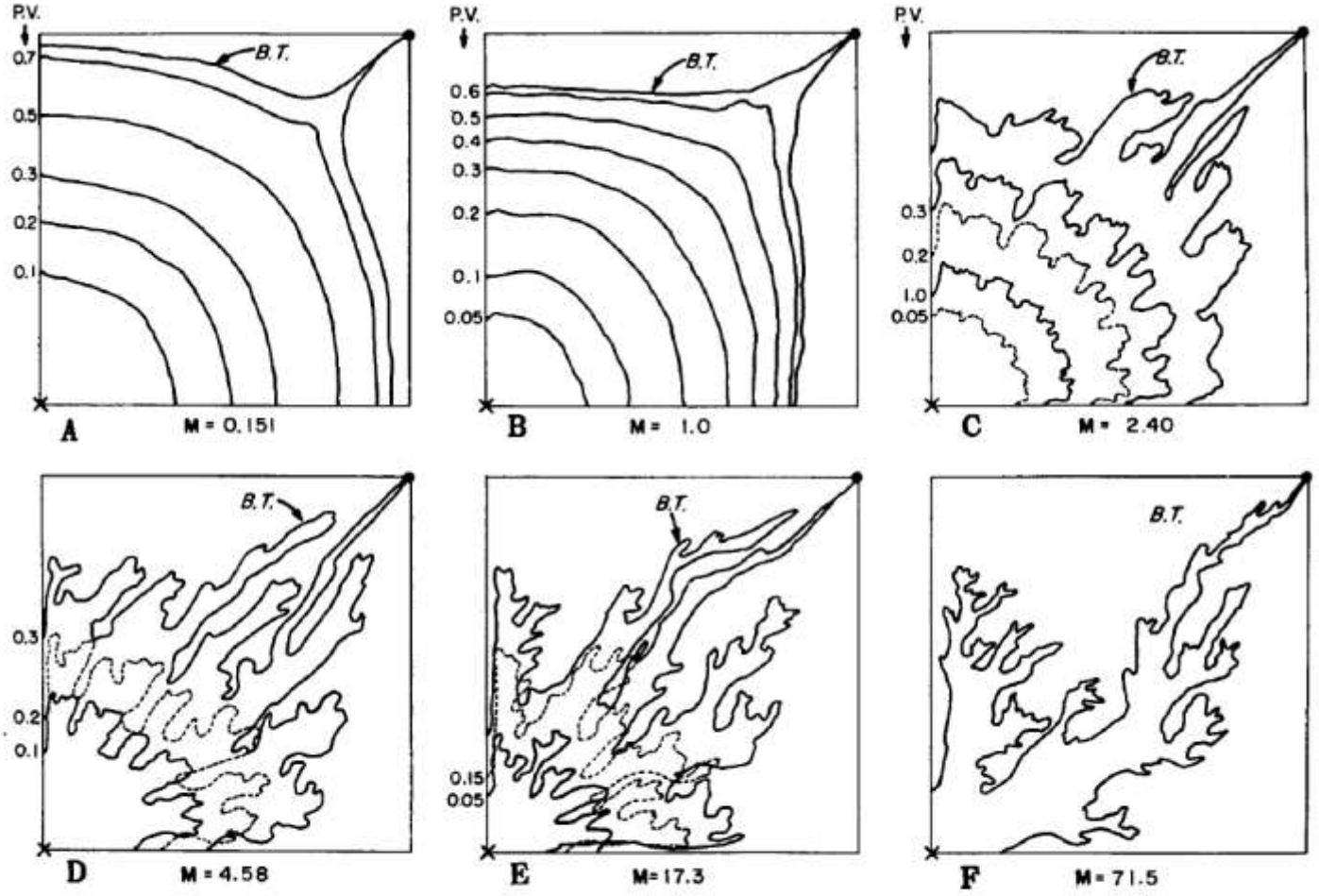
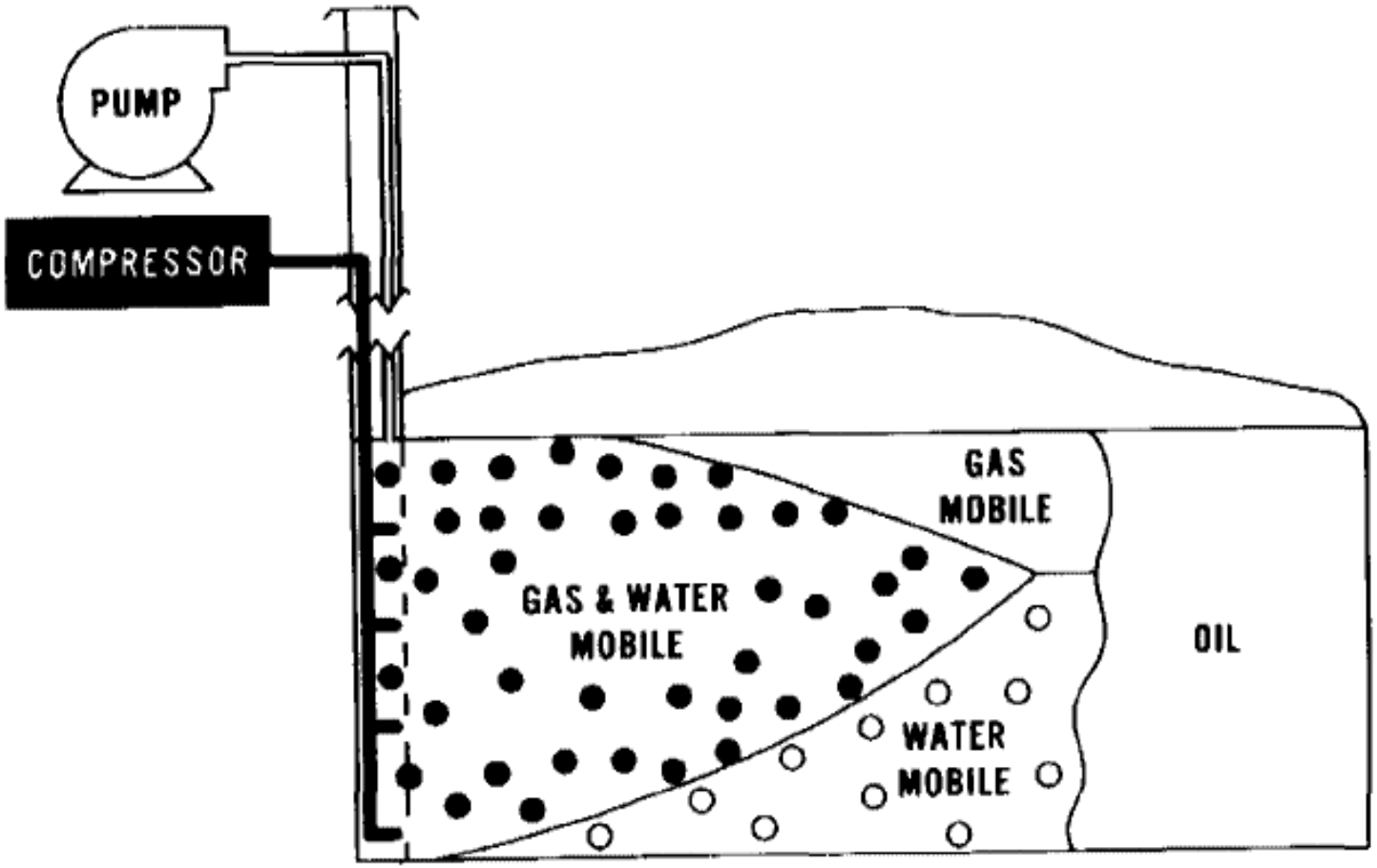


FIG. 5—DISPLACEMENT FRONTS FOR DIFFERENT MOBILITY RATIOS AND INJECTED PORE VOLUMES UNTIL BREAKTHROUGH, QUARTER OF A FIVE-SPOT.

Habermann, B., 1960

Gravity Segregation with WAG



Stone, H.L., 1982

What is the effect of geological heterogeneity on EOR?

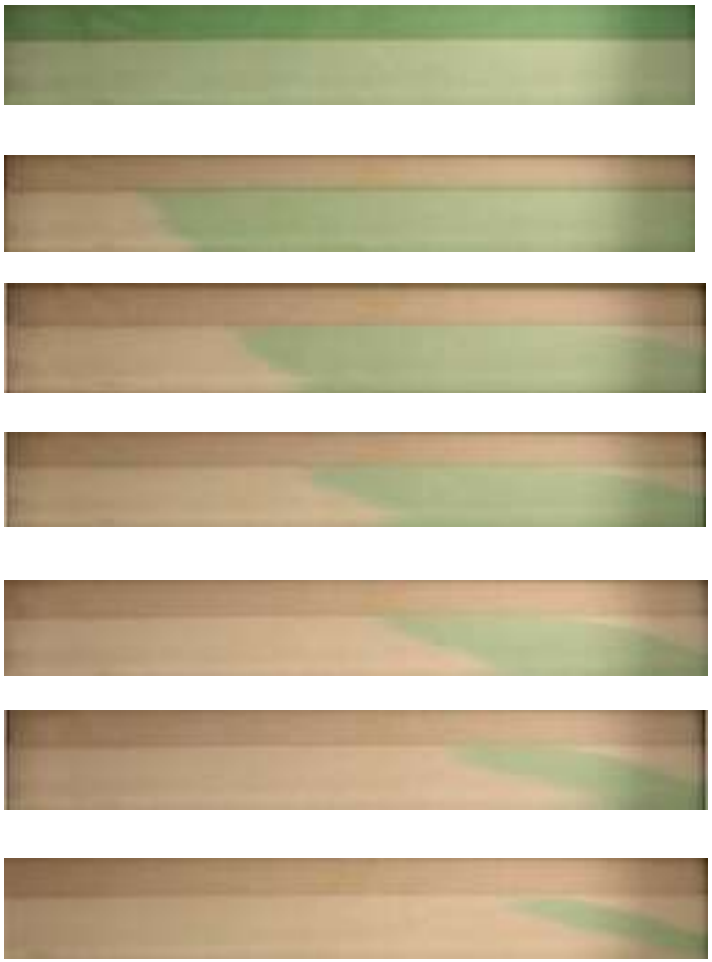
Layered sandpack model with 20:1 permeability Contrast

Li, et al, SPEJ, 2010

Waterflood and WAG

Waterflood or WAG, 4 psi; Sweep is only a function of liquid injected

***fg* =0 water only**



0.0 TPV

1.0 TPV

2.0 TPV

3.0 TPV

4.0 TPV

5.0 TPV

6.0 TPV

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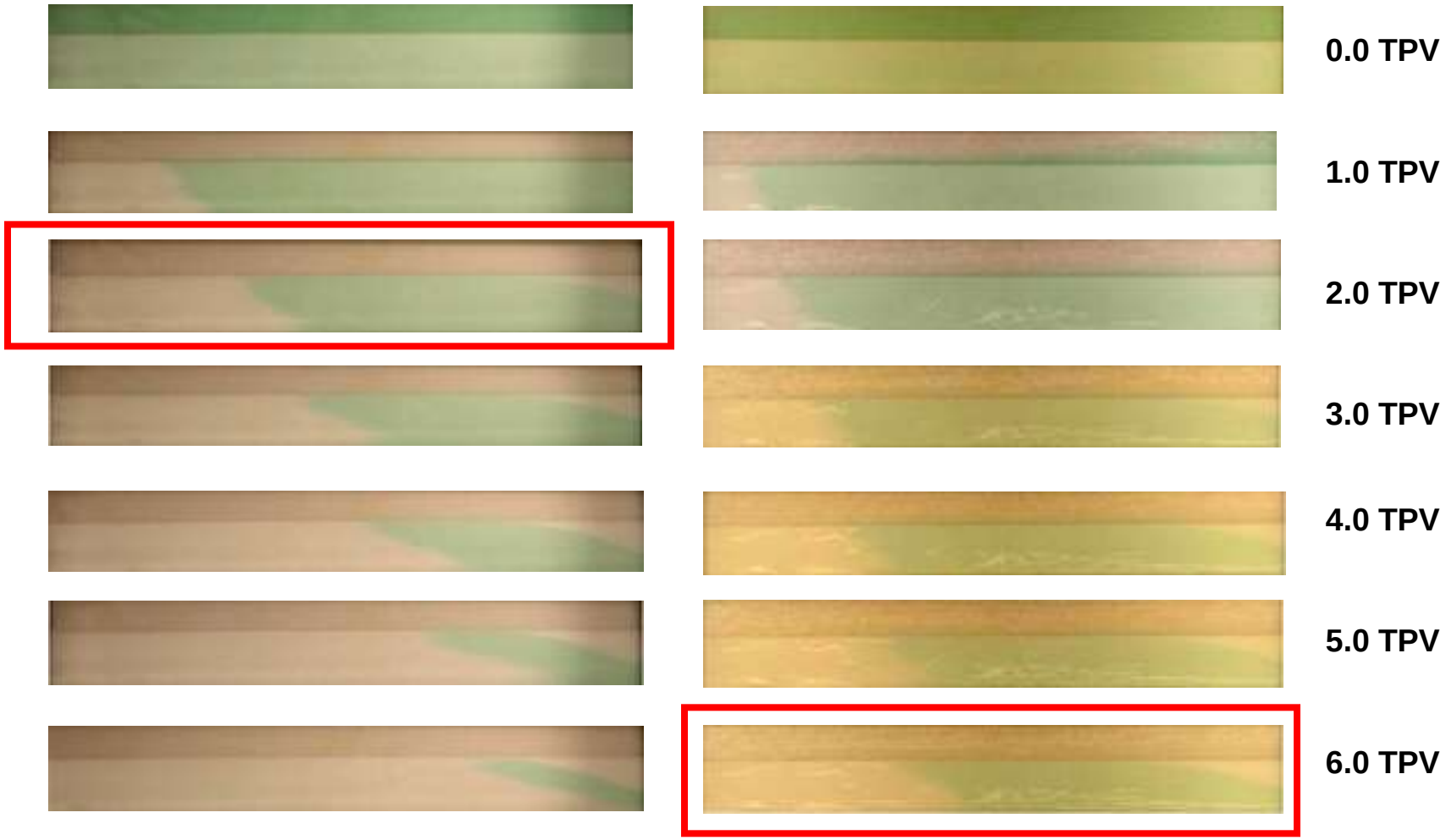
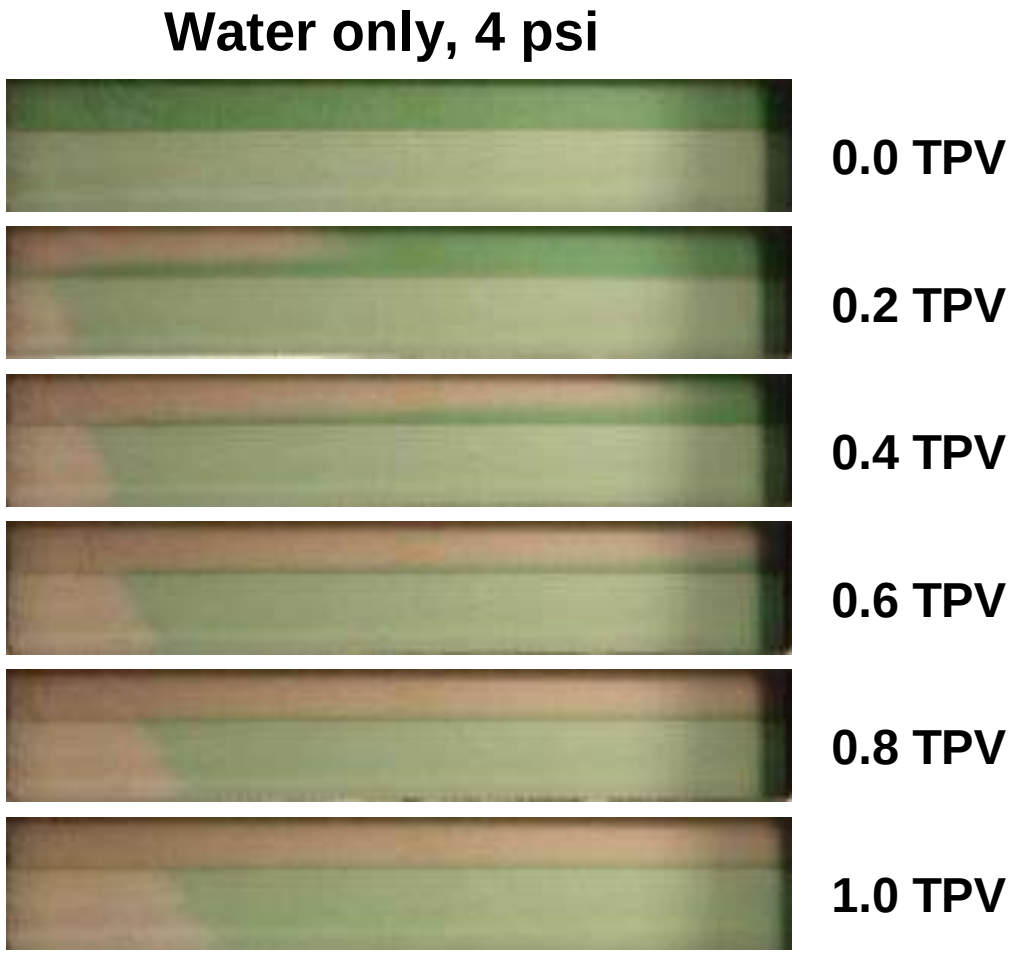


Layered sandpack with 19:1 permeability contrast about half-swept with water only but about completely swept with surfactant-alternated-gas (SAG)



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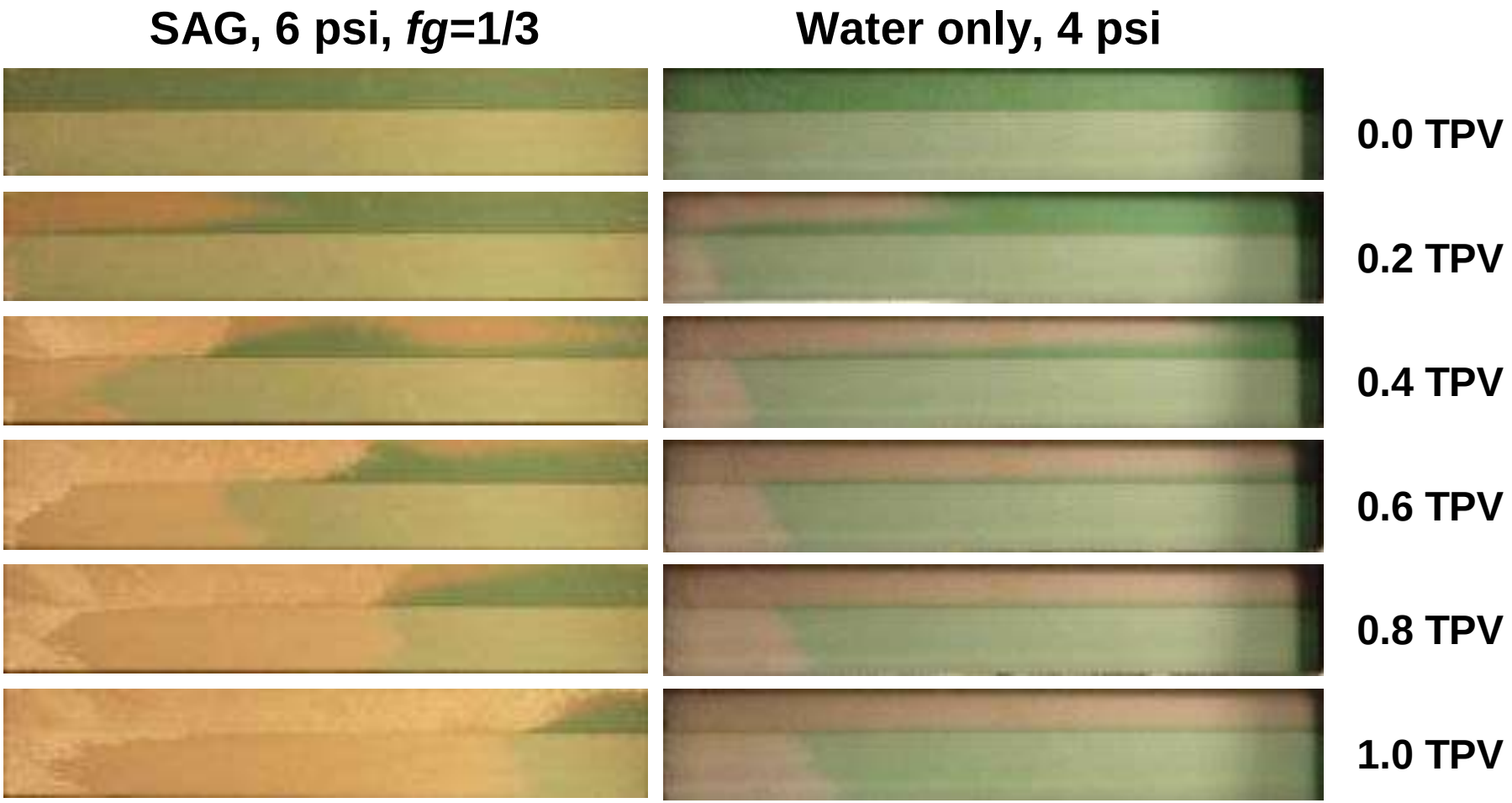
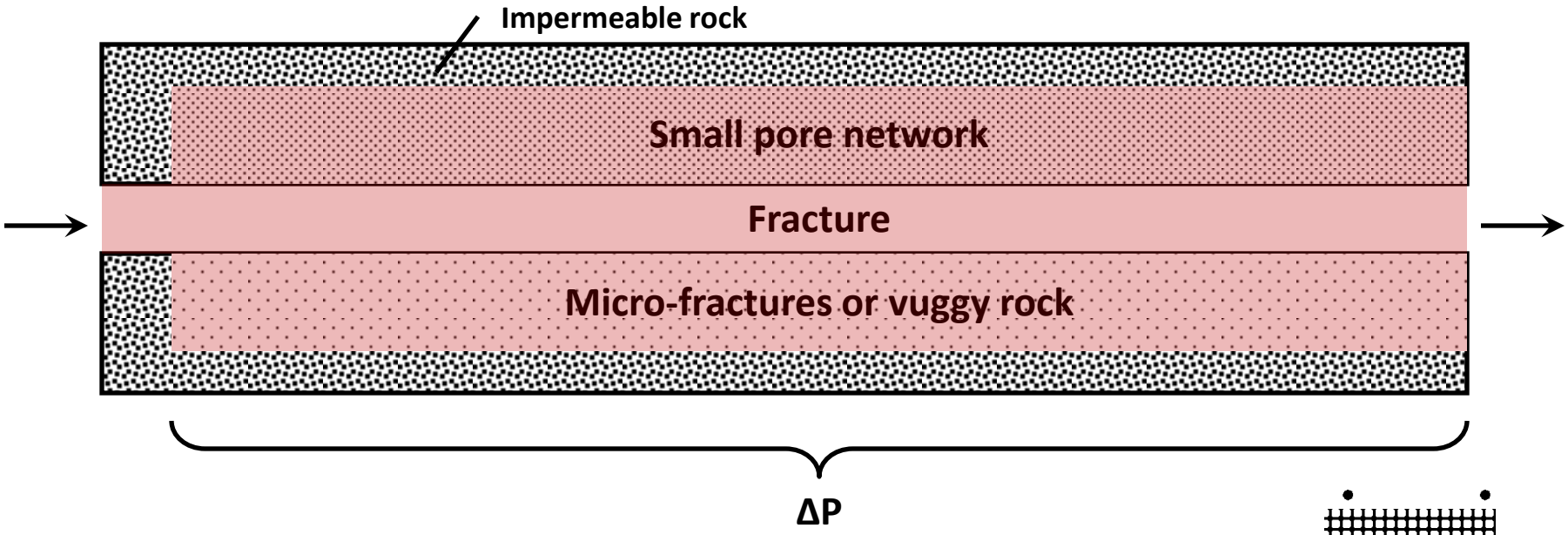
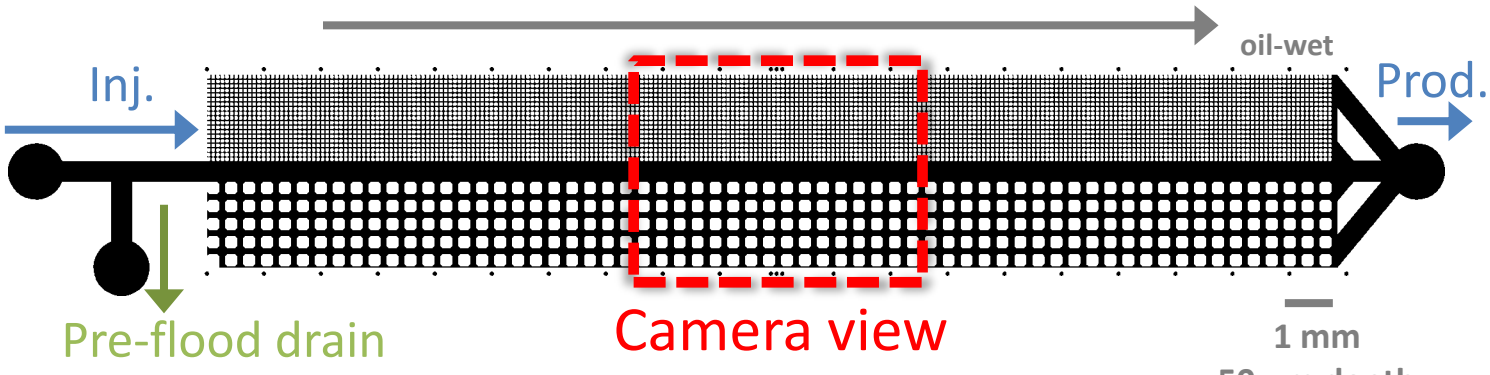
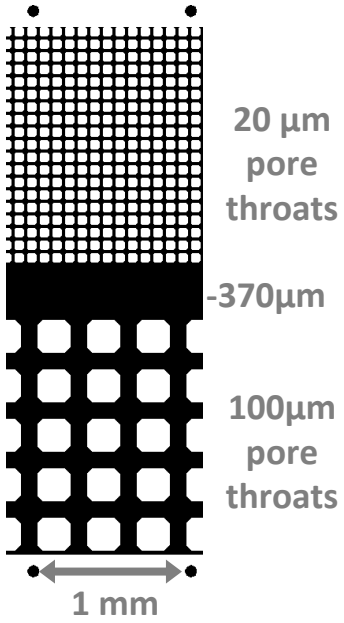


Li, et al, SPEJ, 2010

How does foam displace oil from heterogeneous, oil-wet, fractured system?







Charles Conn, 2013

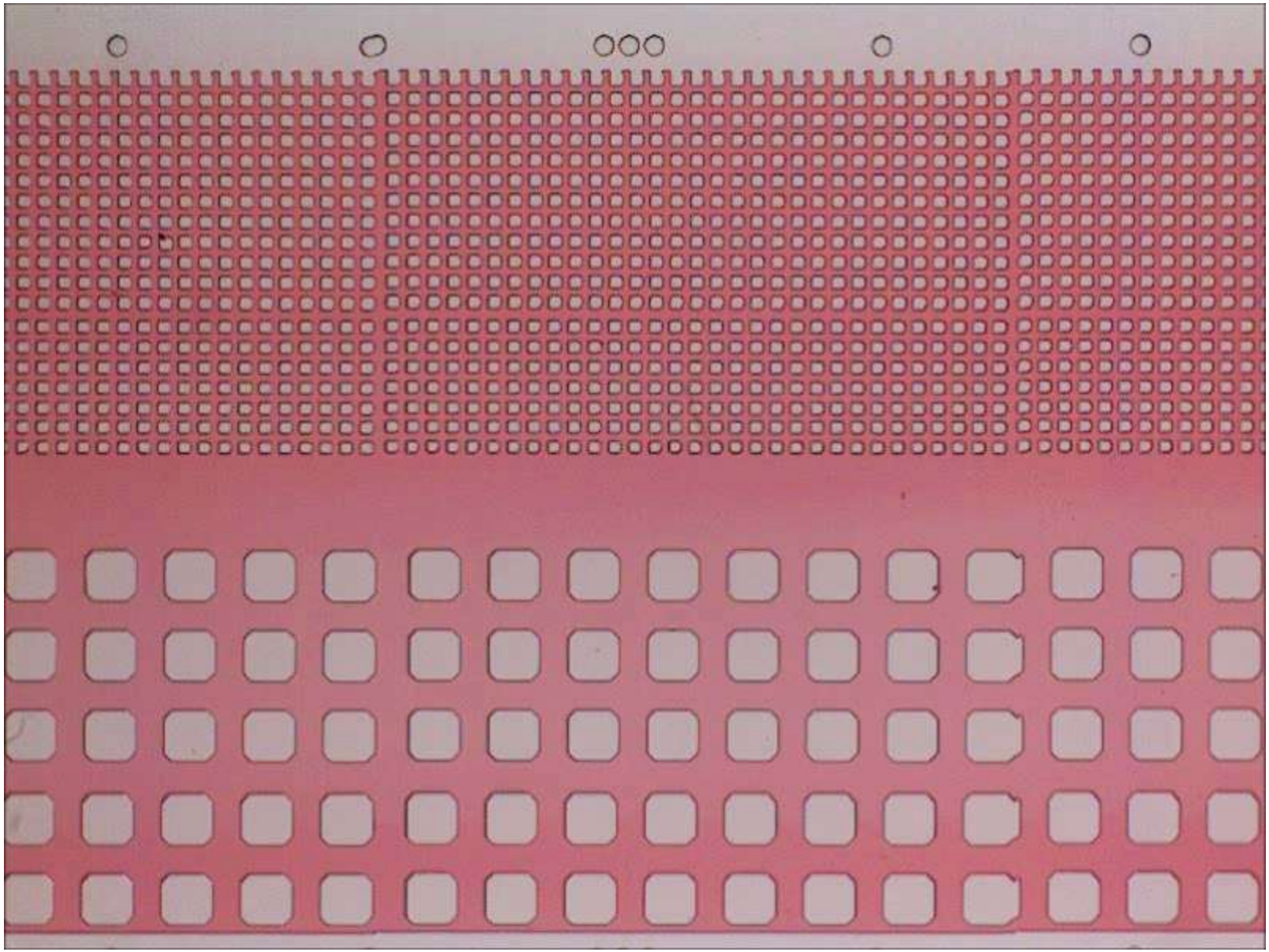
CONTROL

Air & Water

no surfactant

https://drive.google.com/file/d/0BwZmYz9LHrmoSHFZc1Y2ZkF3QzA/edit?usp=sharing

Water 0.05 mL/hr, Air 150 mbar

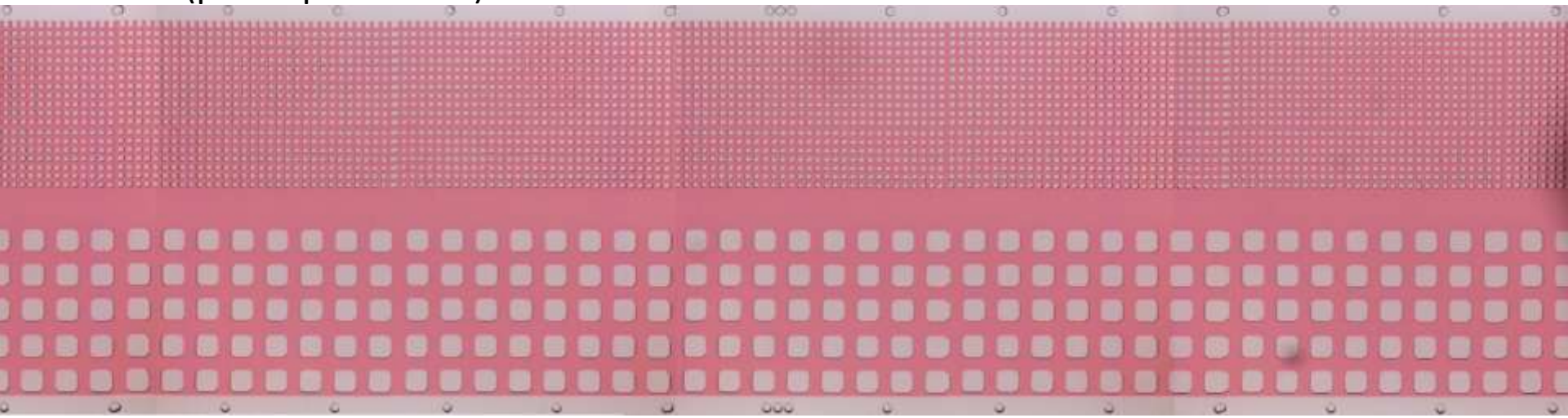


CONTROL

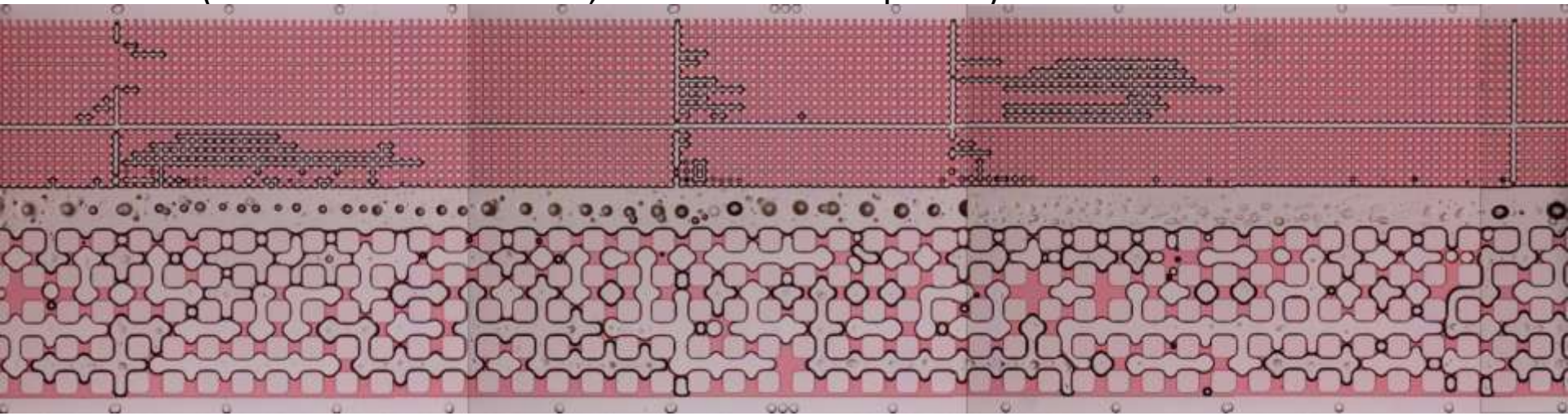
Air & Water

no surfactant

Pre-flood (pink = paraffin oil)



Post-flood (thick dark lamellae = air, thin lamellae = aqueous)



BASE CASE

1% AOS:LB, Seawater ionic strength (NaCl)

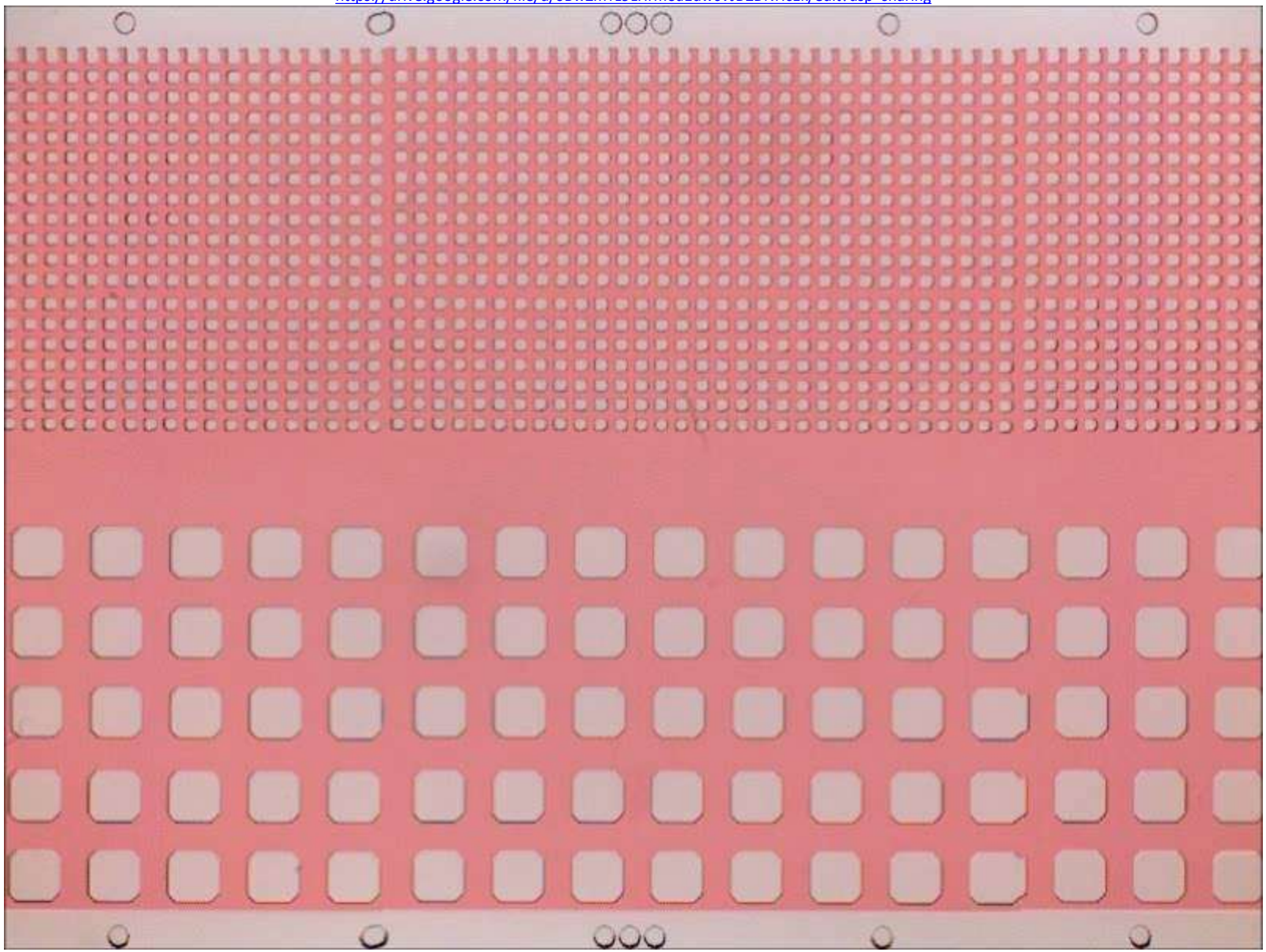
$AOS_{14\text{-}16}$: LB

1 : 1

Surfactant 0.05 mL/hr, Air 150 mbar

(good foamer)

https://drive.google.com/file/d/0BwZmYz9LHrmoa1dwcVJDZDNHcEk/edit?usp=sharing



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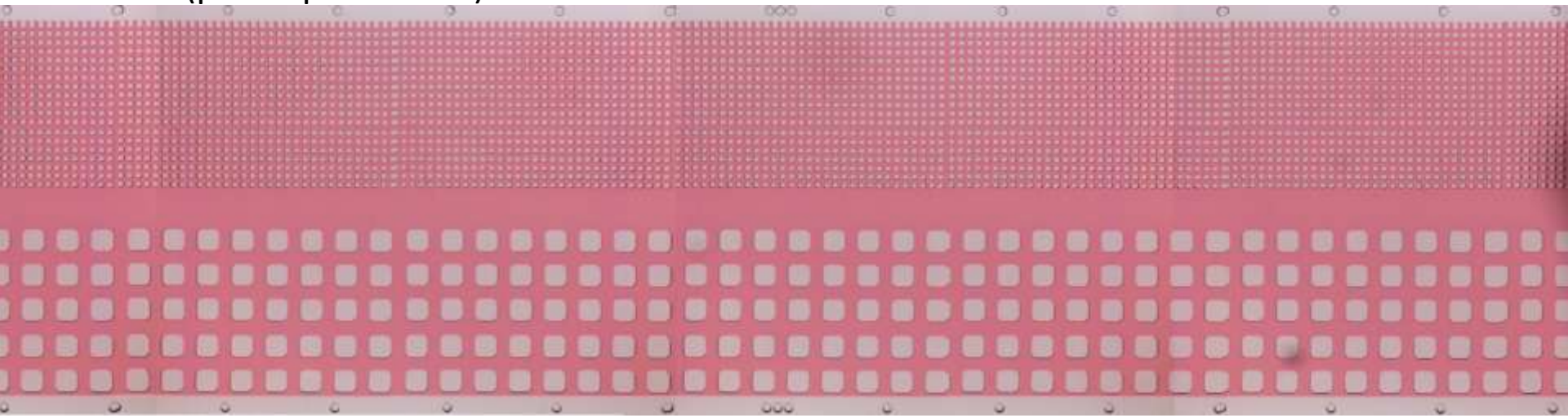

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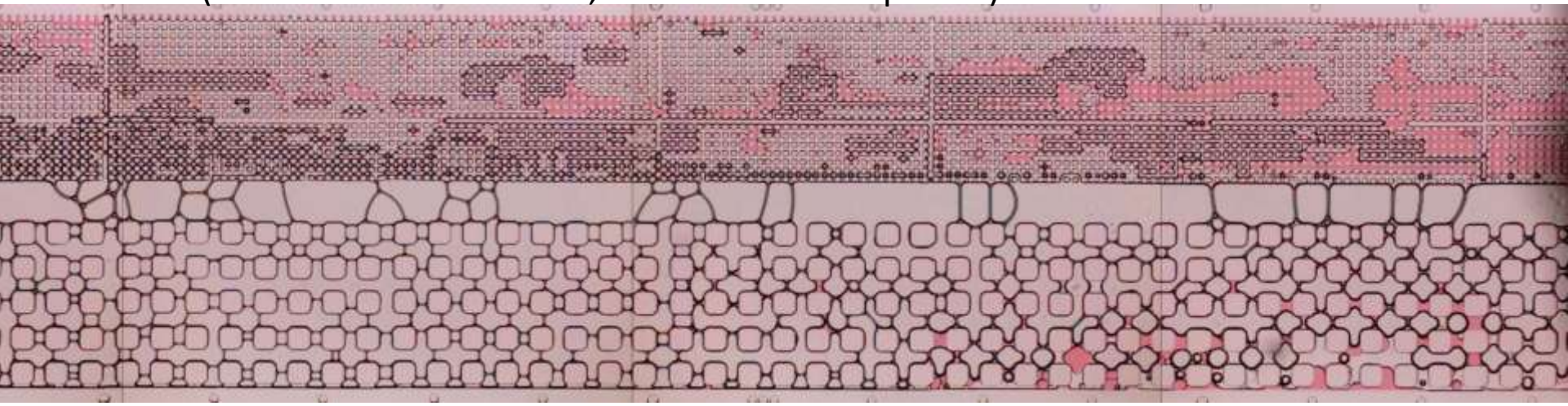
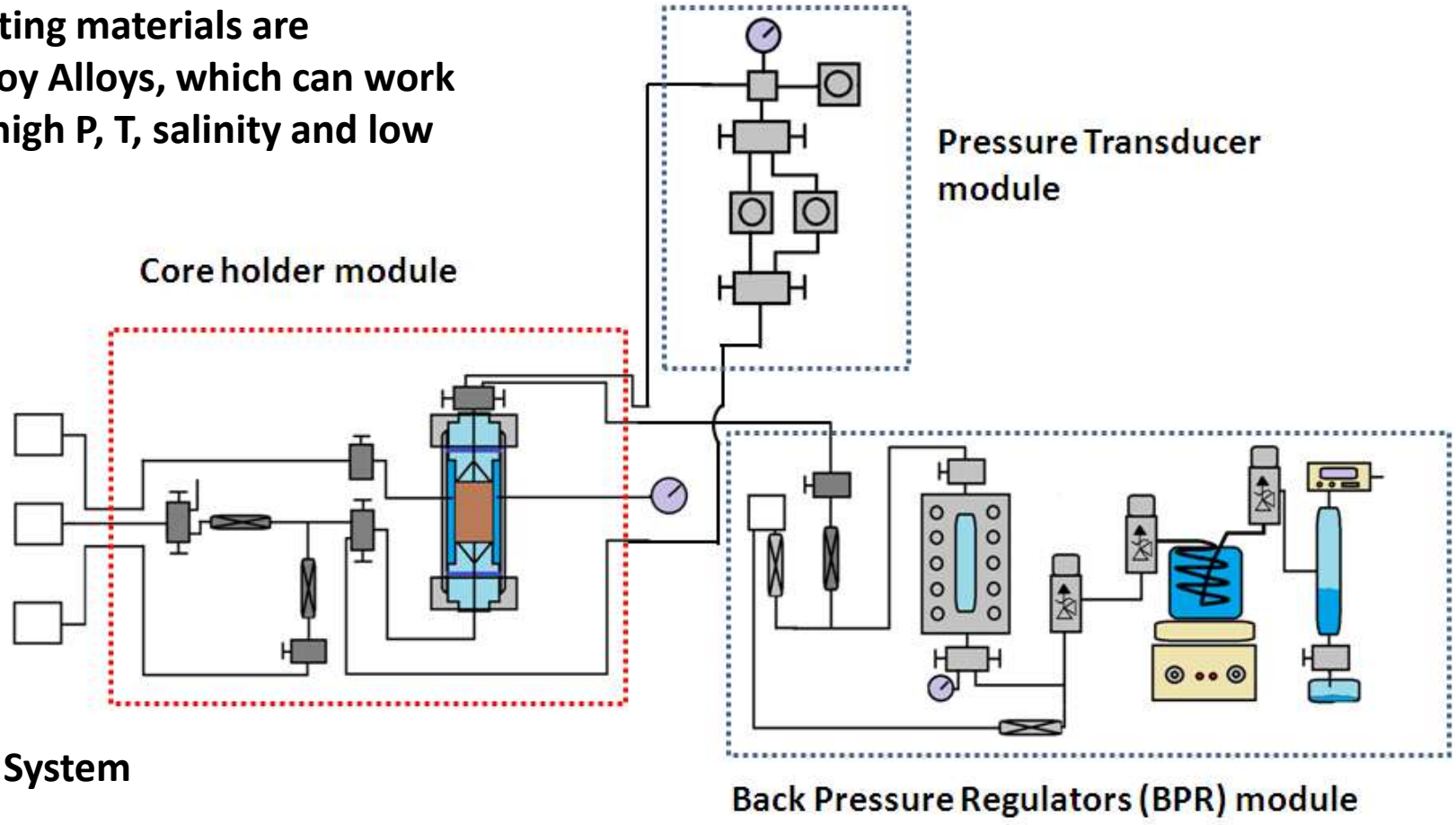


Diagram of the high temperature and high pressure core flooding setup

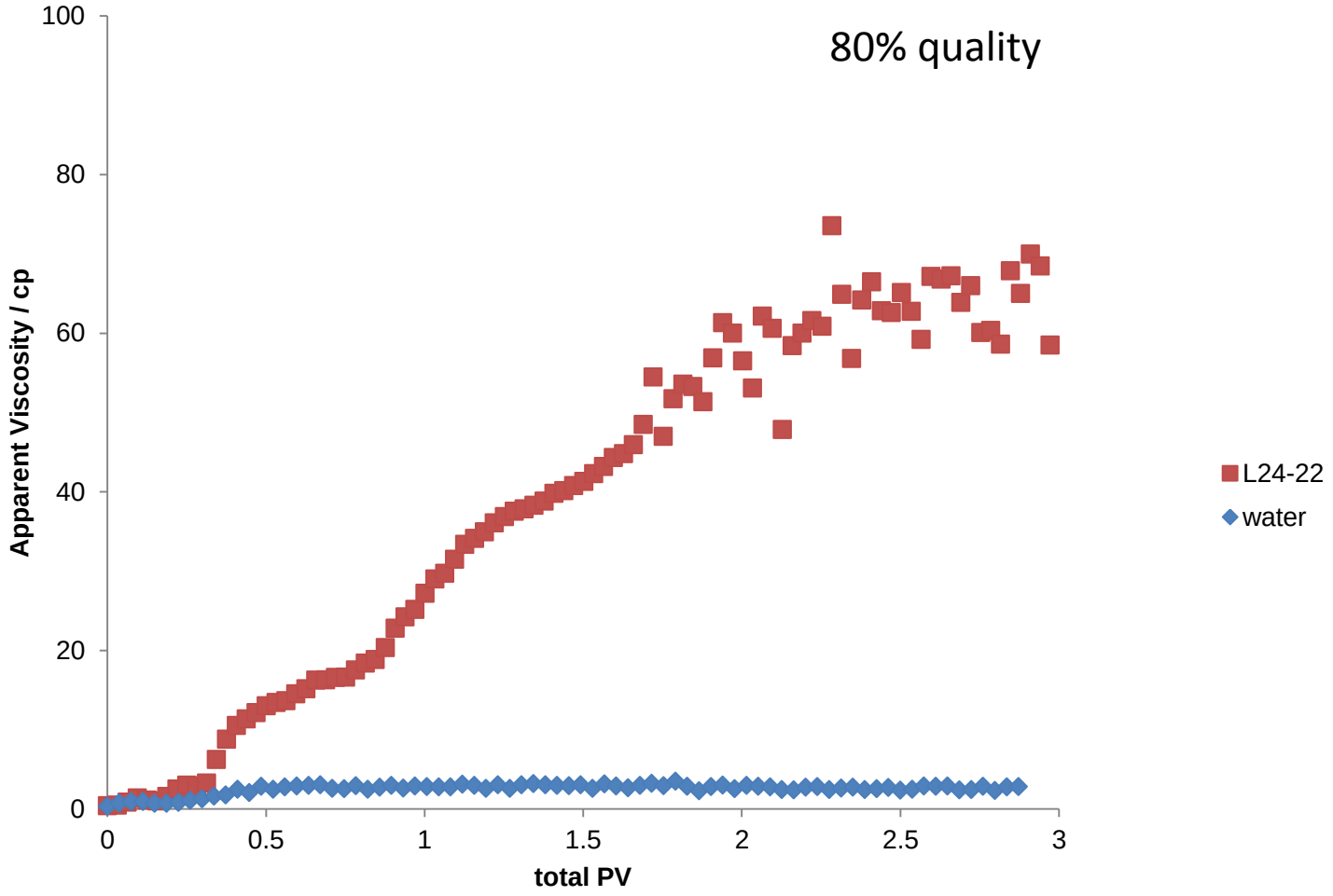
All wetting materials are Hastelloy Alloys, which can work under high P, T, salinity and low pH.



Pumps System

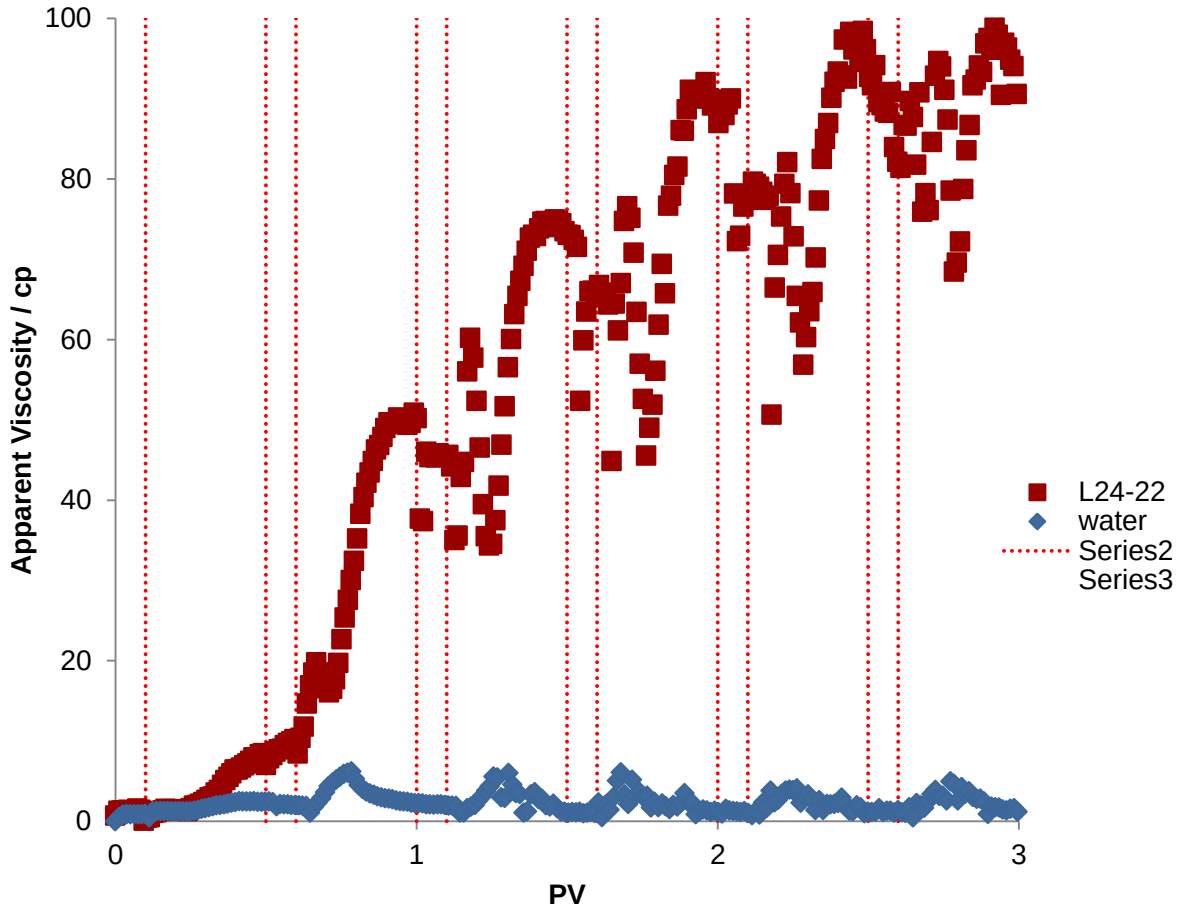
Leyu Cui, 2013

Apparent Viscosity of CO_2 Co-Injected with Water or Non-Ionic Surfactant Solution in Dolomite Core



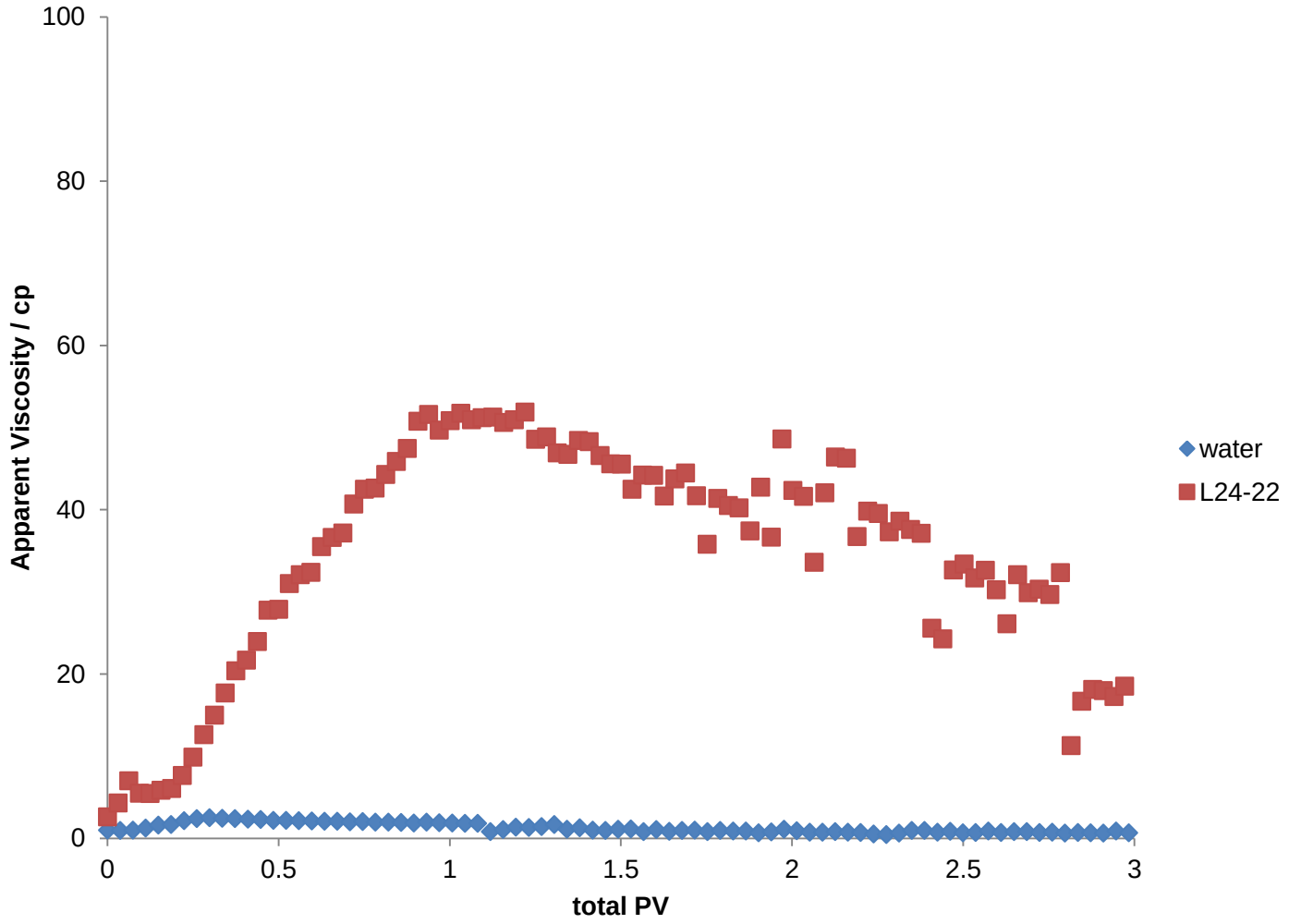
Leyu Cui, 2012

Apparent Viscosity of WAG or SAG



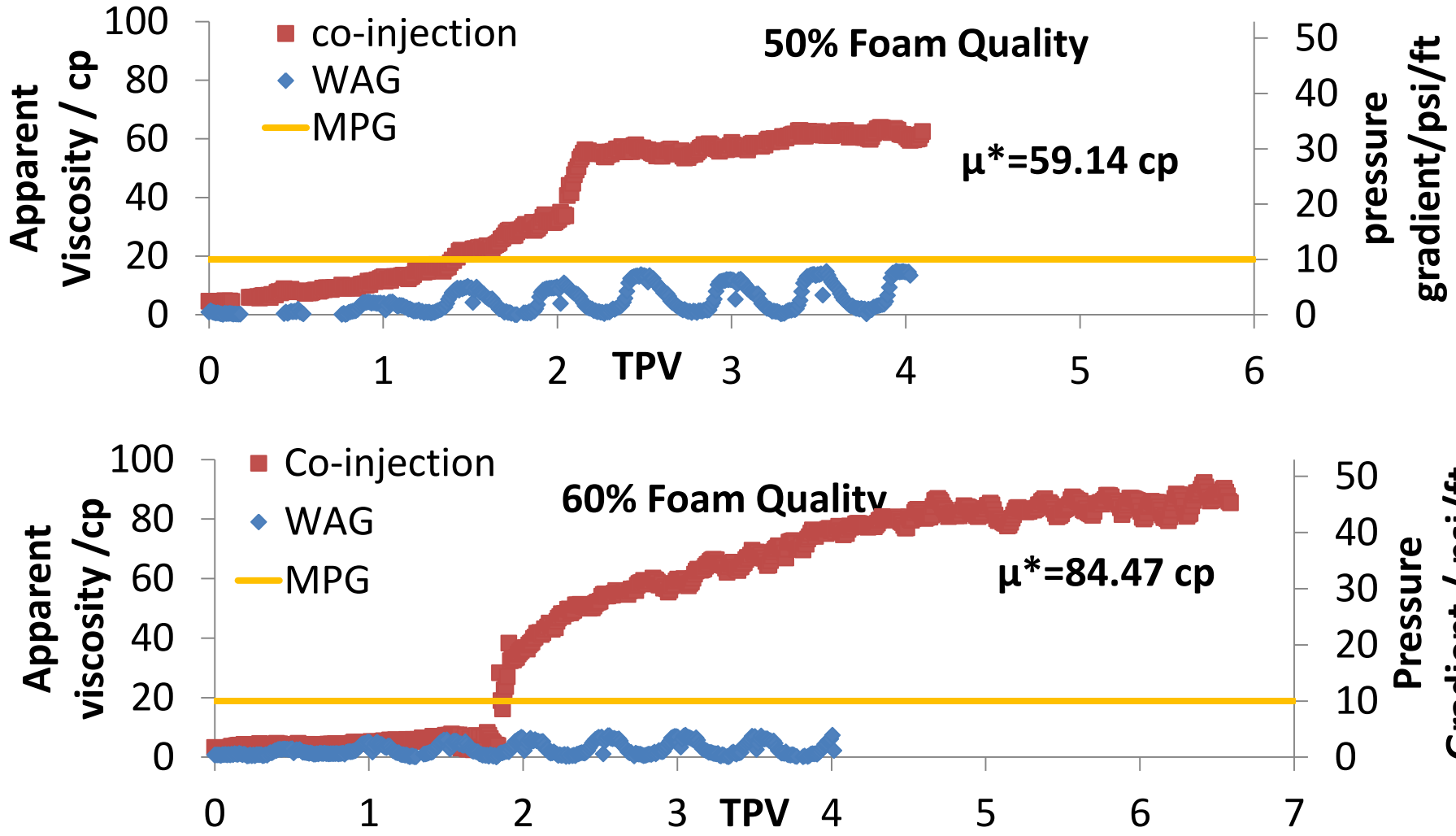
Leyu Cui, 2012

Apparent Viscosity of CO_2 Displacing Water or Non-Ionic Surfactant Solution in Dolomite Core



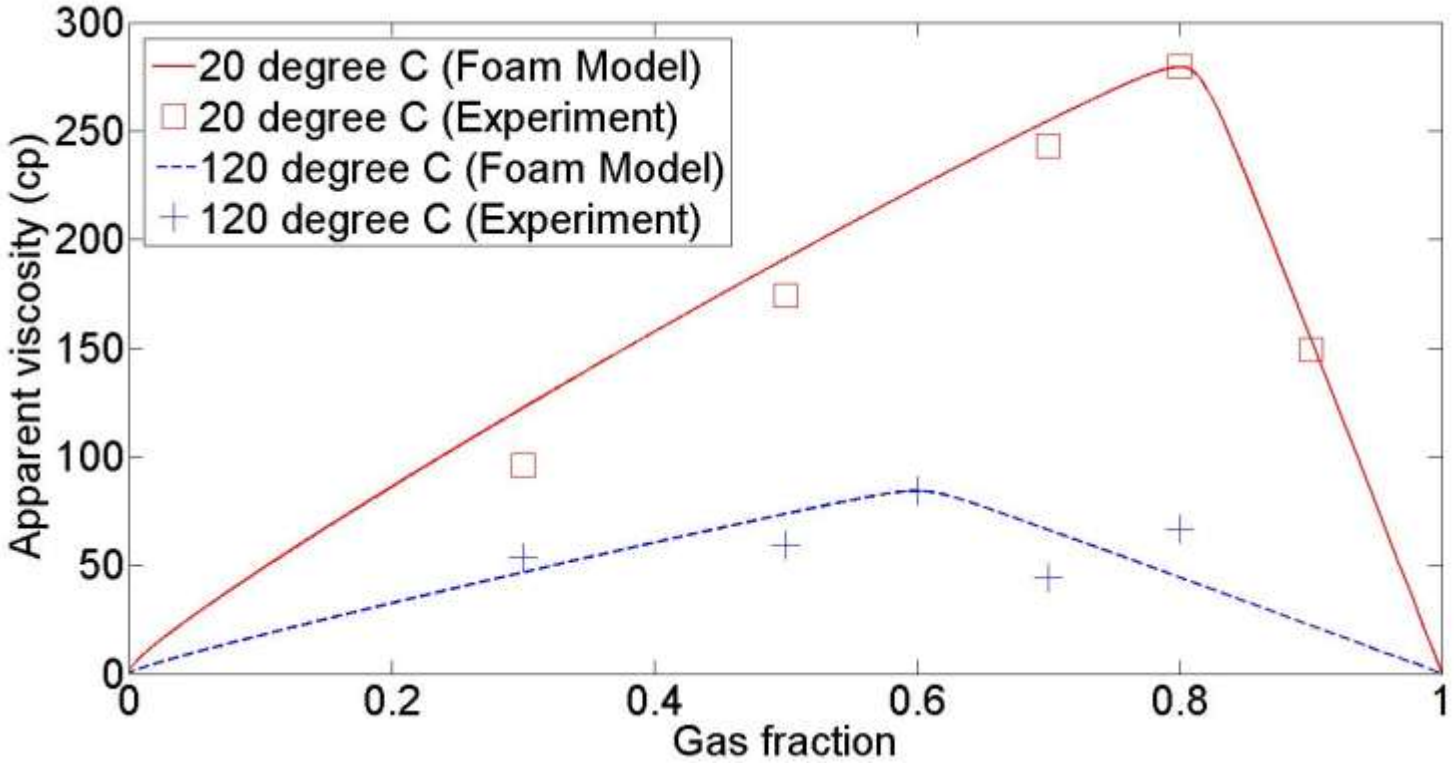
Leyu Cui, 2012

C12/Brine and CO_2 Foam at 120 °C and 3400 psi



Leyu Cui, 2013

Comparison of viscosity at 20 and 120 °C for C12/Brine and CO_2 Foam



krw^0=0.5; krg^0=0.1768; S_wc=0.33; S_gr=0.2; n^w=2.8; n^g=1.1; (Bennion, 2008)

μ_w=0.2381 cp; μ_g=3.935×10^{-2} cp;

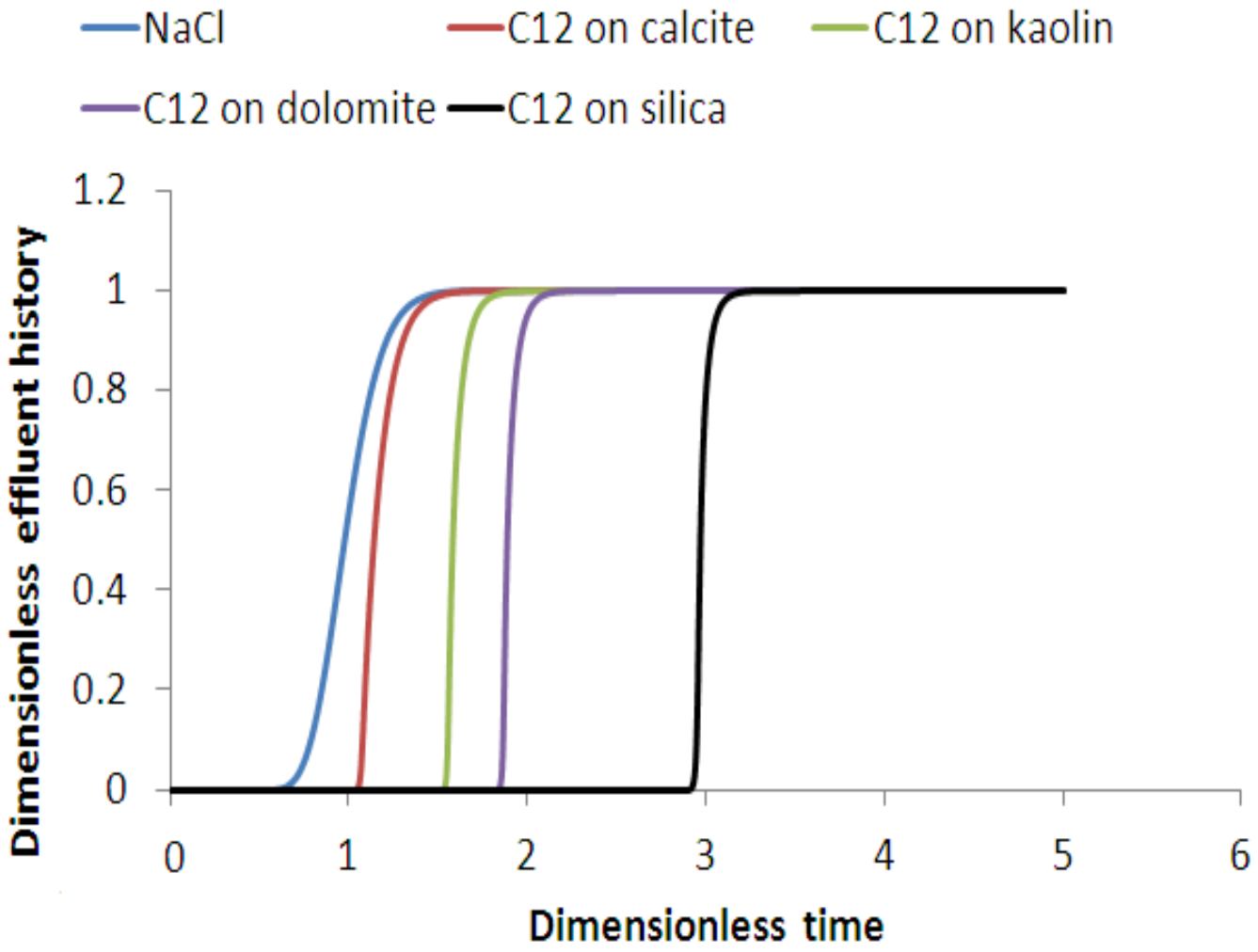
epdry=10000

Leyu Cui, 2013

Transport of surfactant is limited by adsorption on rock

- Adsorption of anionic surfactant is generally lower on sandstone compared to carbonate
- Adsorption on nonionic surfactant is generally lower on carbonate compared to sandstone
- Nonionic surfactant has cloud-point limitation at higher temperature
- Cationic or nonionic/cationic surfactant has potential for carbonate formation at high temperature

Surfactant Adsorption is Dependent on Surfactant/Mineral Interaction



Conclusions

- **CO_2 EOR can be improved by foam mobility control to improve reservoir sweep**
- **Foam improves sweep in layered systems**
- **Surfactant must be matched with reservoir parameters to limit surfactant adsorption**