NORTEX 2017

Enhancing Carbon Dioxide Enhanced Oil Recovery

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Outline of Presentation

- West Texas Carbonates

- Middle East Reservoirs
  - Reservoir conditions
  - Surfactants
  - Solubility in brine and CO_2
  - Dependence on salinity and temperature
  - Adsorption

- Conclusions

Nonionic surfactant for low-temperature West Texas carbonate formation

- **Silurian Core Sample**
- **Diameter=1.5 in.**
- **Length= 7.6 cm= 2.99 in.**
- **Permeability= 48.9 md**
- **L24-22: alcohol (22 EO) with linear hydrophobe (C12-14) from Huntsman, the activity of solution is 1(wt)% /DI (assume the activity is 100%).**

Chen, et al., 2015

Flooding Condition

- **Pressure= 3400 psi**

- **Temperature=room temperature, ~25 °C**

- **Flooding Speed: 4 ft/day**

- **Injection Schemes: Co-injection, WAG or SAG and 100% CO_2 continuous injection**

Pressure Gradient Expressed as Apparent Viscosity

- Apparent viscosity is used to describe the foam strength, which is calculated by Darcy's law:

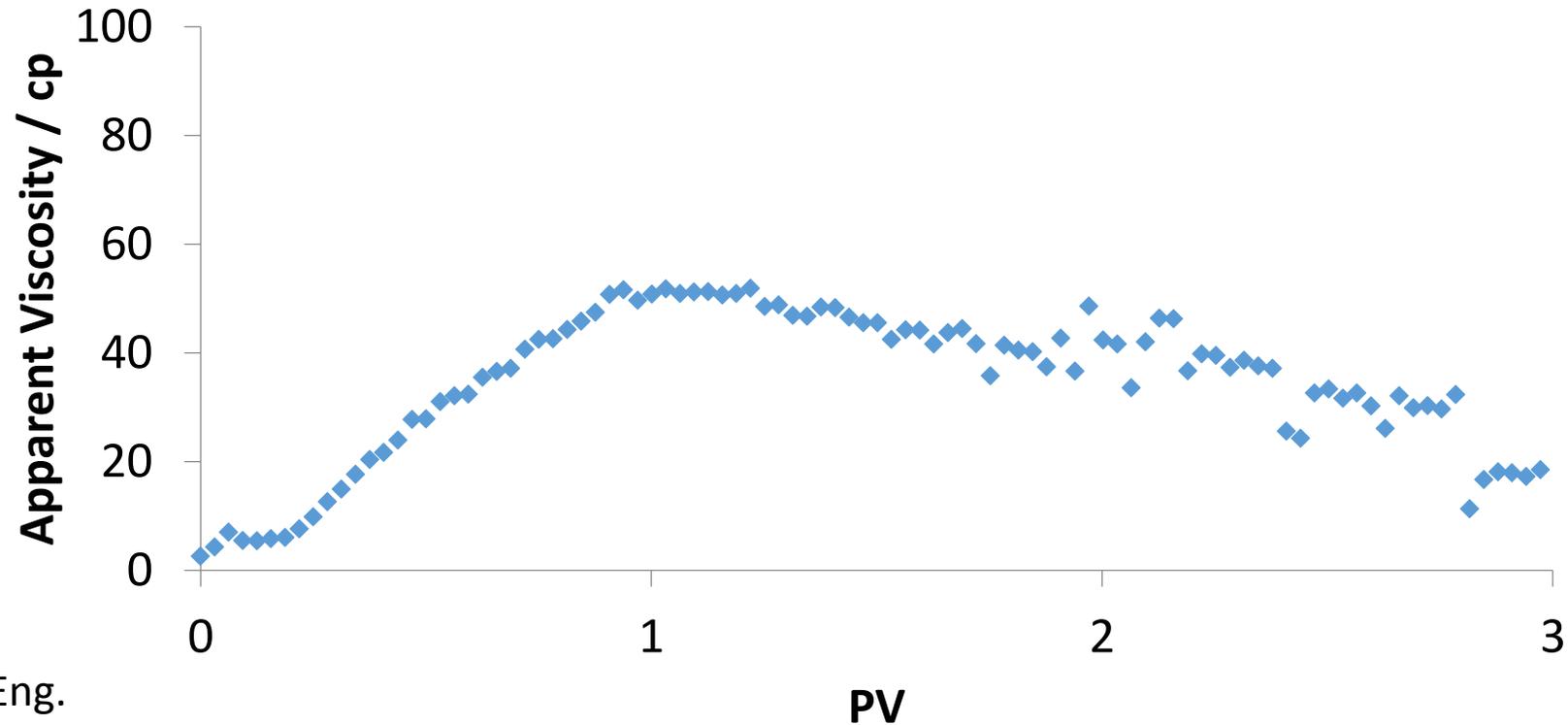$$\mu_{app} = -\frac{k\,\nabla p}{\left(u_w + u_{CO2}\right)}$$

where μ_{app} is foam apparent viscosity, k is core permeability, u is the total superficial velocity and p is the pressure gradient.

SAG, 80% CO_2 and 20% L24-22 /DI (1wt%), at 4 ft/day
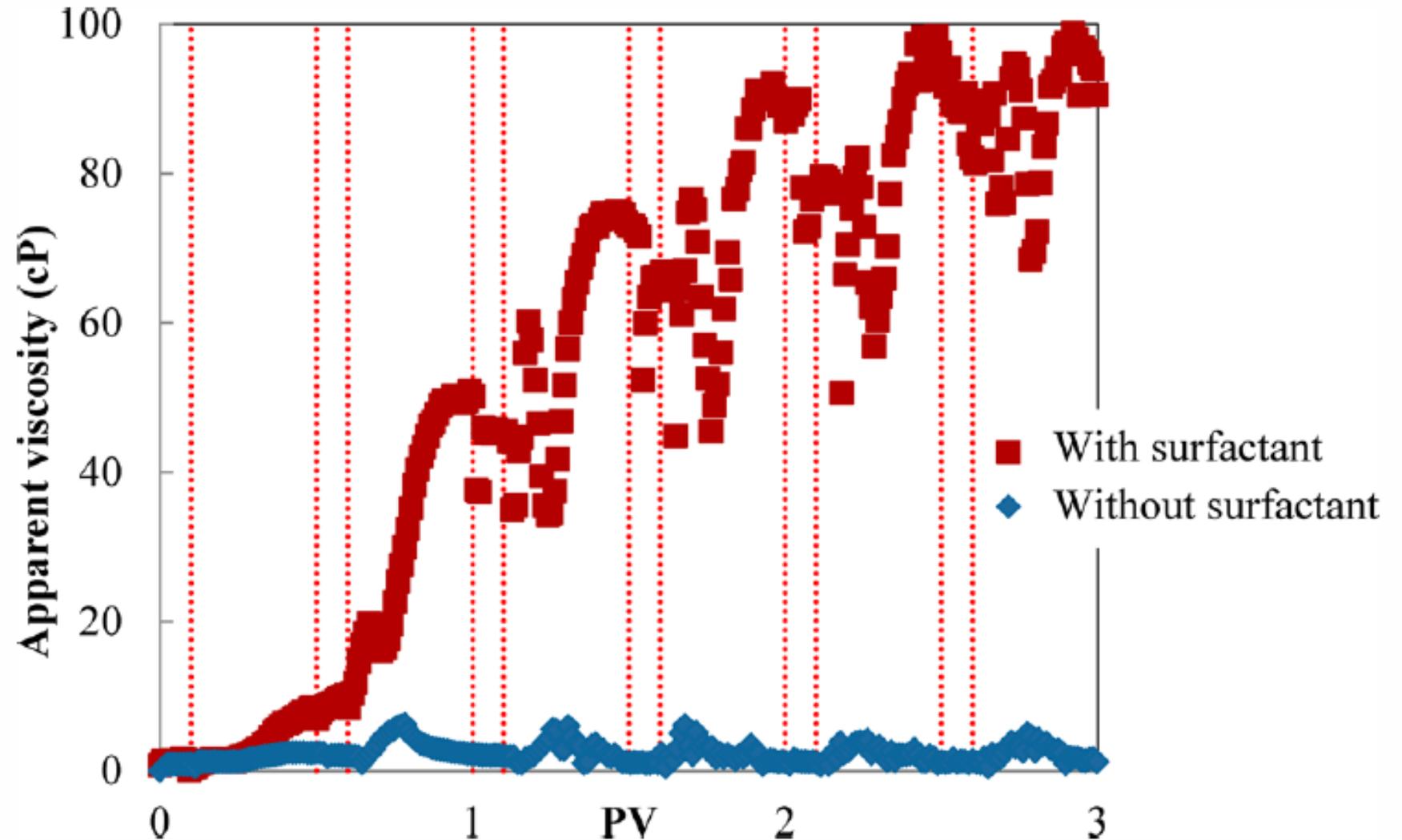
Chen, et al., 2015, Ind. Eng. Chem. Res., 54, 4252-4263.

Continuous 100% CO_2 Injection , at 4 ft/day

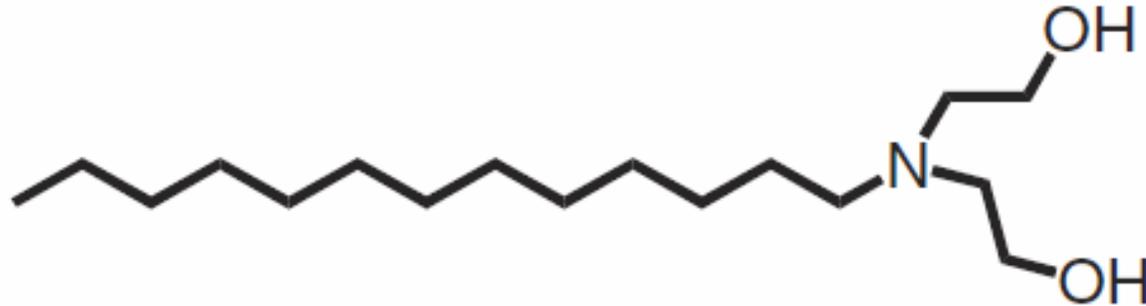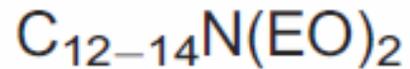Chen, et al., 2015, Ind. Eng.
Chem. Res., 54, 4252-4263.

4 PV of L24-22/DI (1wt%) solution are injected into core at 4 ft/day, before inject CO_2

Middle East Flooding Conditions

- Temperature=120 °C
- Pressure = 3,400 psi
- Salinity = 22% TDS
- Carbonate Formation

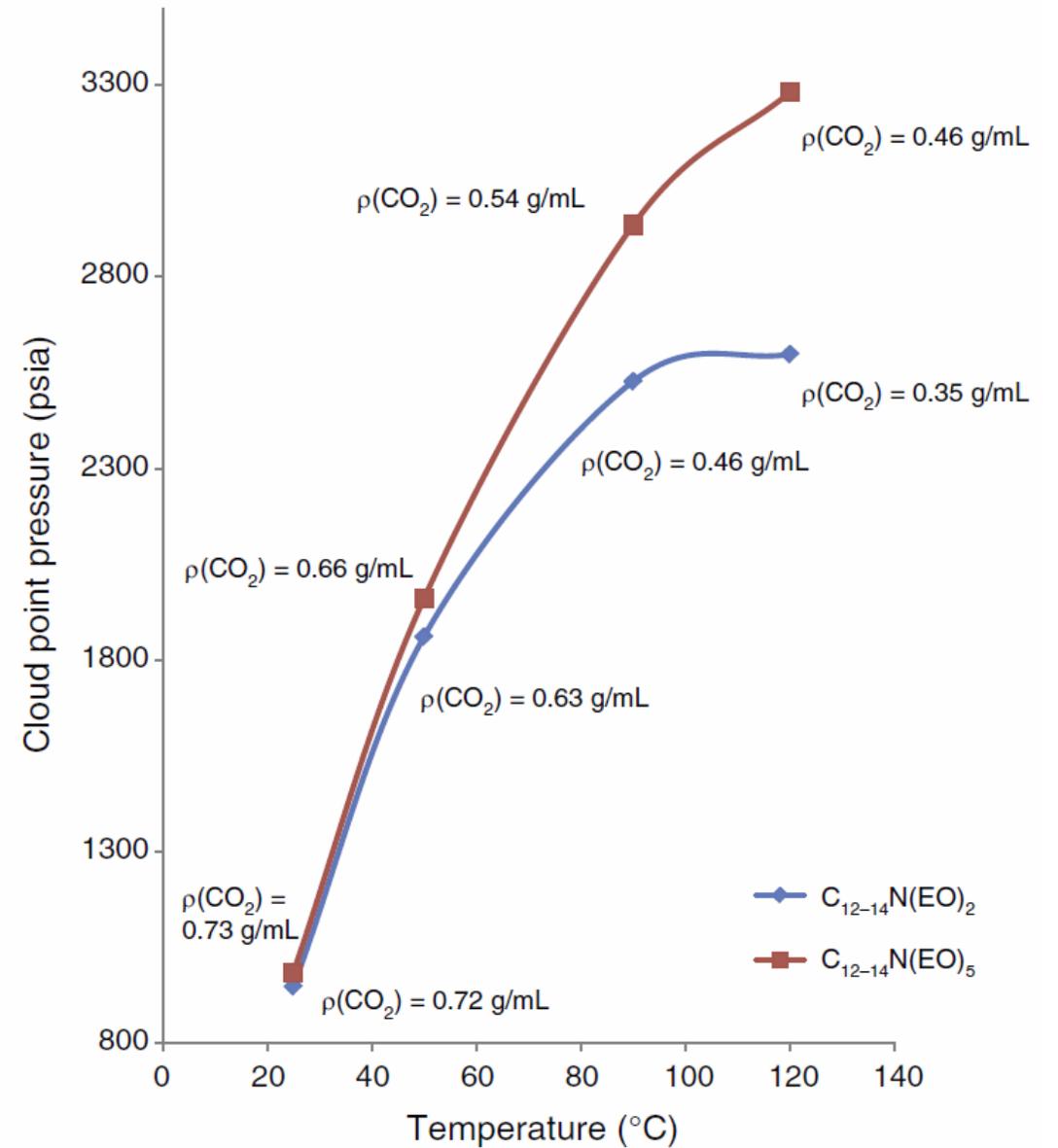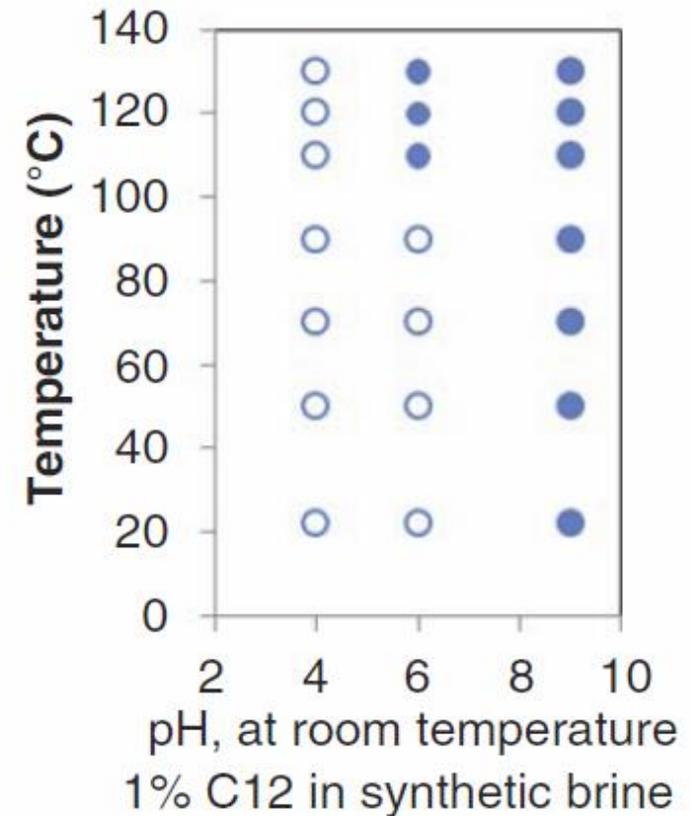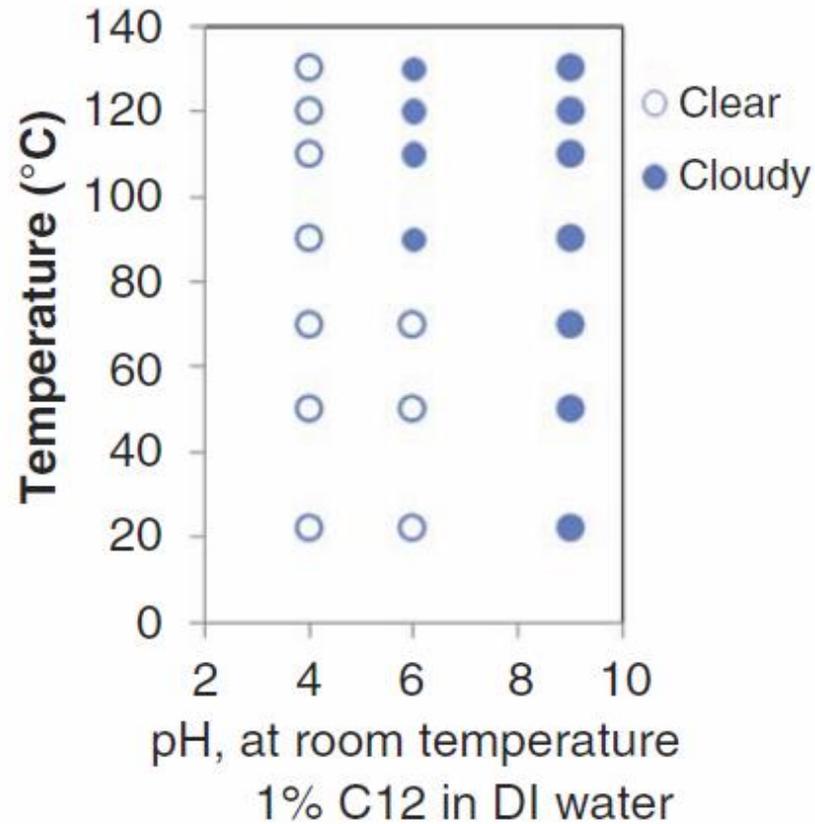# Surfactant for High Temperature, High Salinity, Carbonate Reservoirs

Ethomeen C/12

$C_{12-14}N(EO)_2$

OH

N

OH

Hydroxyl groups added hydrophilicity
Raised solubility in water

Chen, et al., 2014, *SPEJ*

Surfactant can be dissolved in CO$_2$

Chen, et al., 2014, *SPEJ*

Surfactant is Soluble in Water or Brine at Low pH

Brine in Equilibrium with CO_2 at High Pressure is pH 4
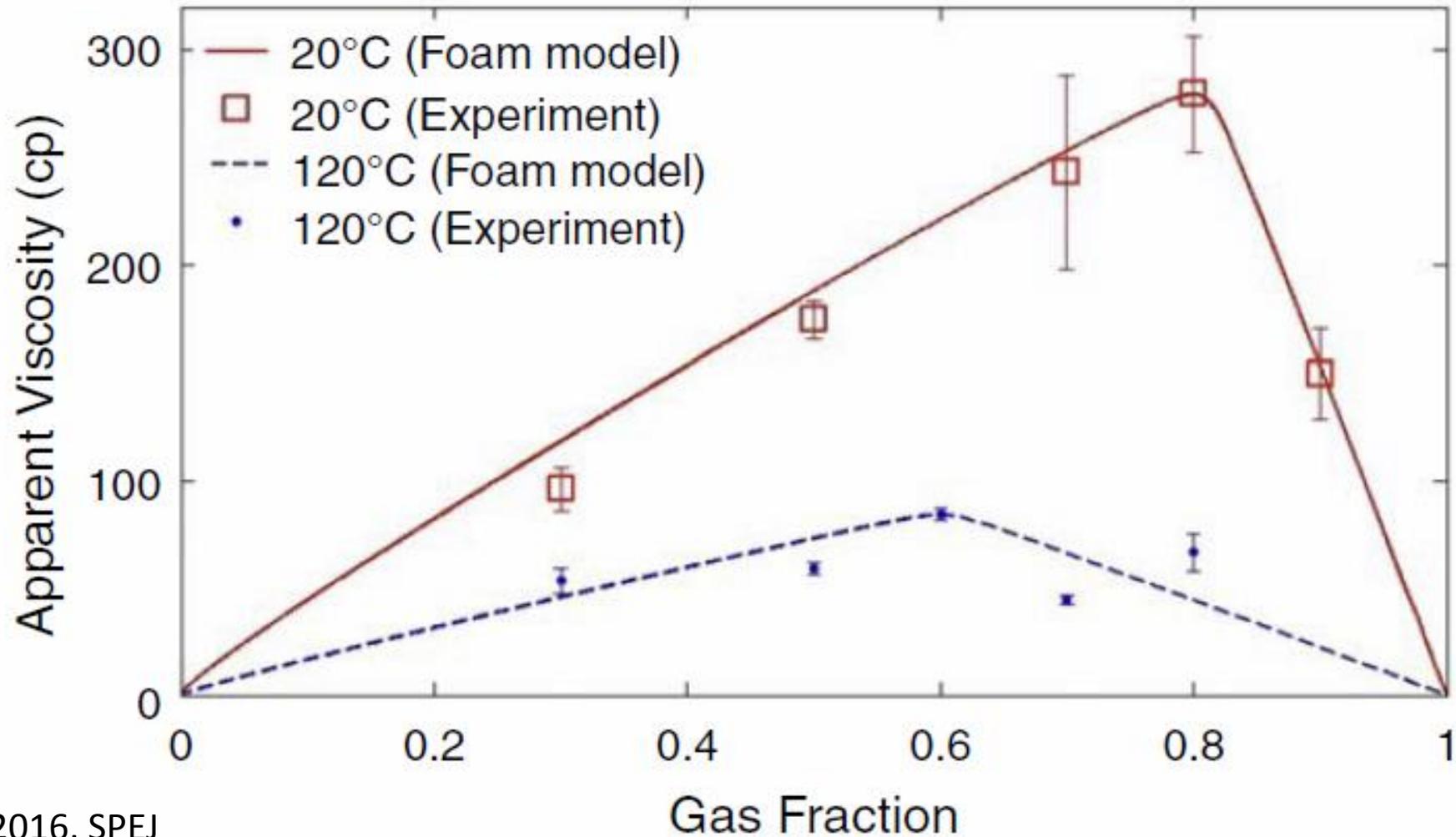

Cui, et al., 2015

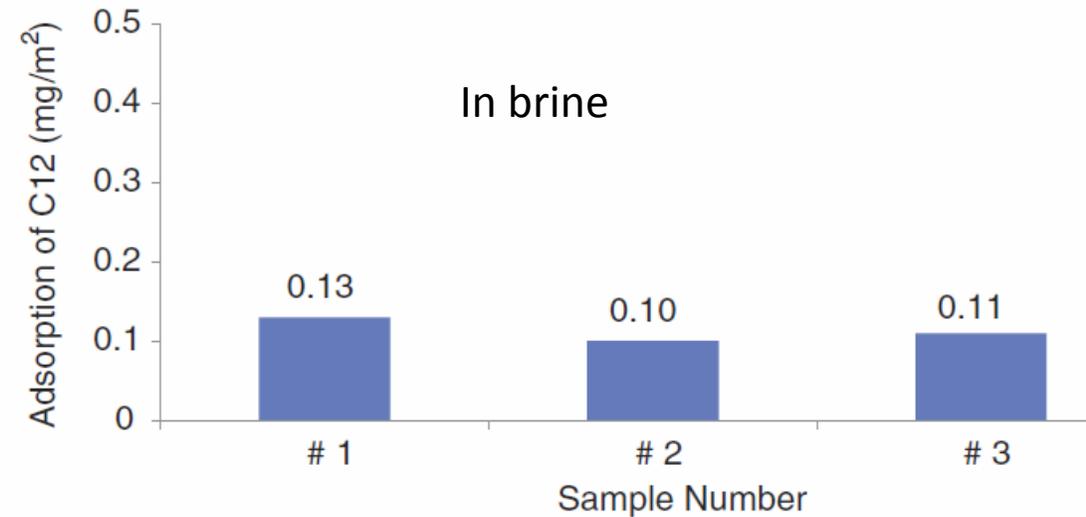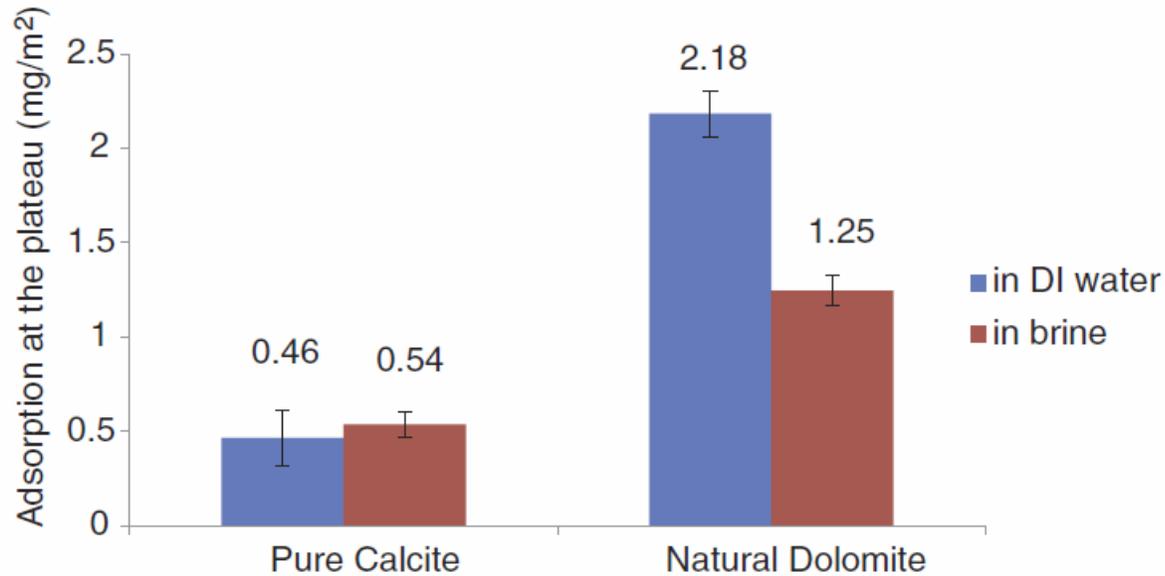# Minimum Pressure Gradient is Needed to Generate Foam In Situ; Then Shear-Thinning

Cui, 2016, SPEJ
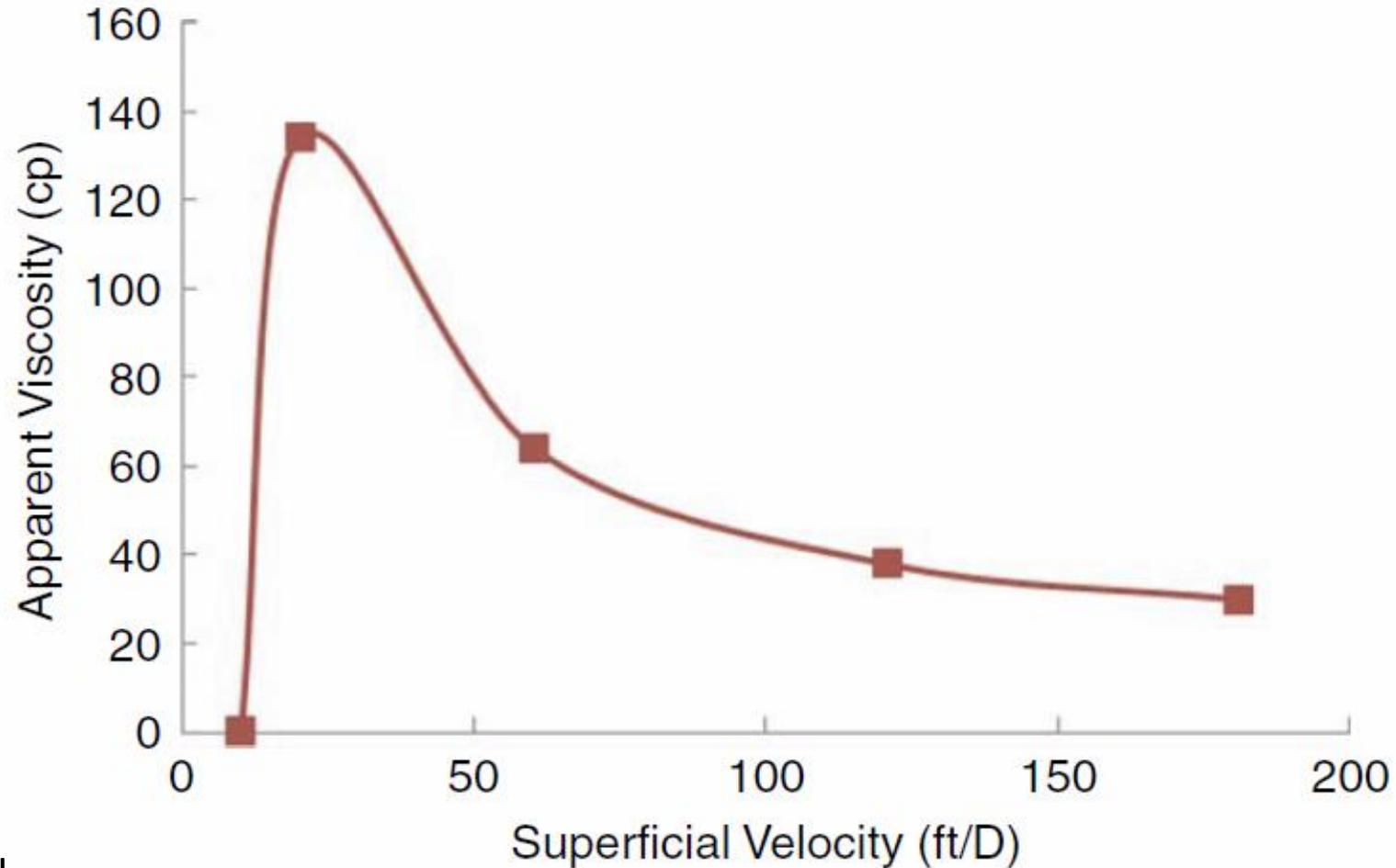
Effect of 22% TDS Brine on Foam Strength
Room Temperature

Cui, 2016, SPEJ
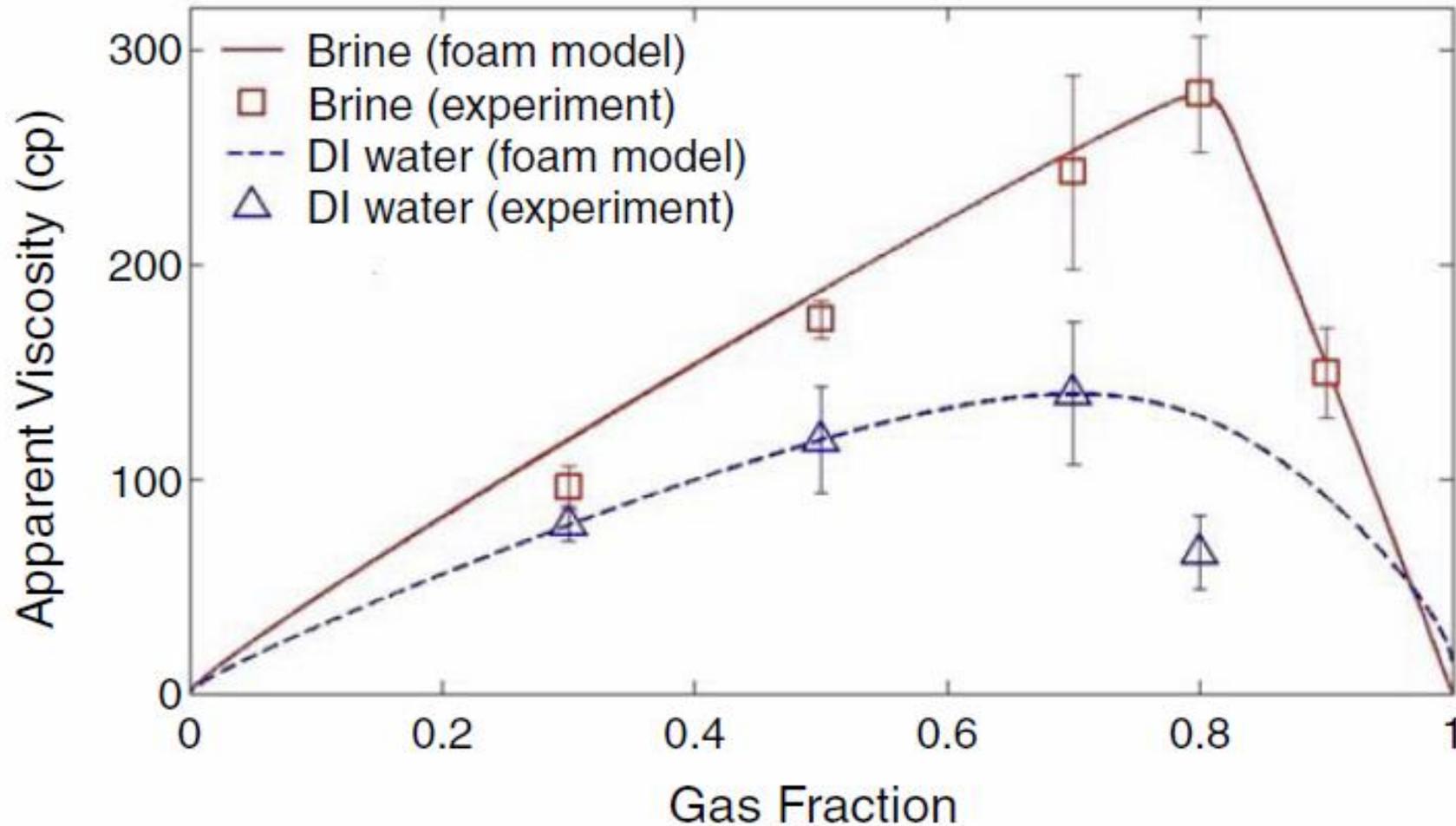
Effect of Reservoir Temperature on Foam Strength
22% TDS Brine

Cui, 2016, SPEJ

Adsorption of C/12 on Carbonate Rocks

Cui, et al., 2015 *SPEJ*

Formation Material

BET area= 4.0 m²/g

Conclusions

- CO_2 is available from natural sources and industrial sites
- Low viscosity of CO_2 results in poor sweep efficiency
- CO_2 can be made viscous by dispersing as foam
- Nonionic surfactant is adequate for West Texas
- Middle East has high temperature and high salinity
- Switchable nonionic to cationic surfactants are candidates for Middle East carbonate reservoirs