

# **CO<sub>2</sub> Foam Flood in Fort Stockton Sandstone Reservoir**

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# Reservoir properties

- Sandstone reservoir with carbonate intervals
- Reservoir  $T=35^{\circ}\text{C}$
- Initial reservoir pressure  $\sim 300\text{psi}$



# OUTLINE

- **Surfactant stability**
- Surfactant solubility in brine
- Surfactant adsorption
- Bulk foam test and foam flood in core

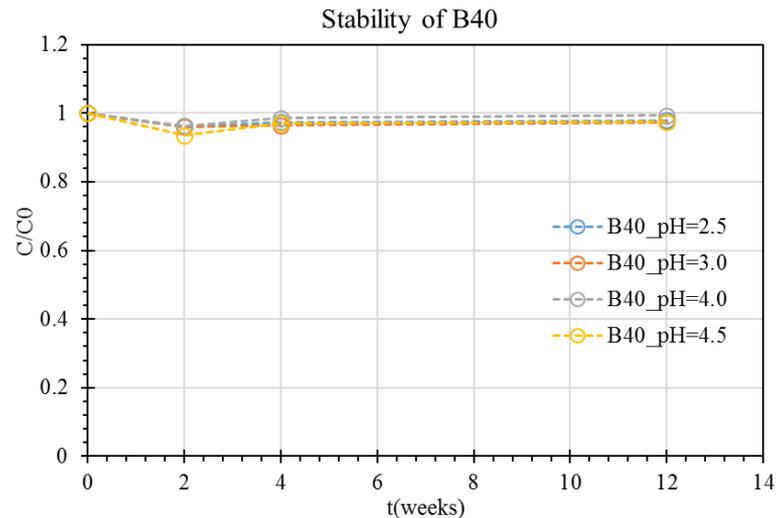
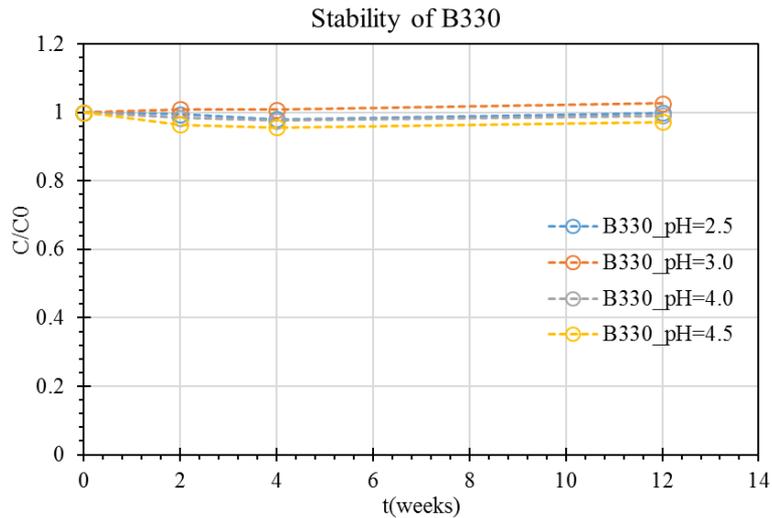


# Surfactants

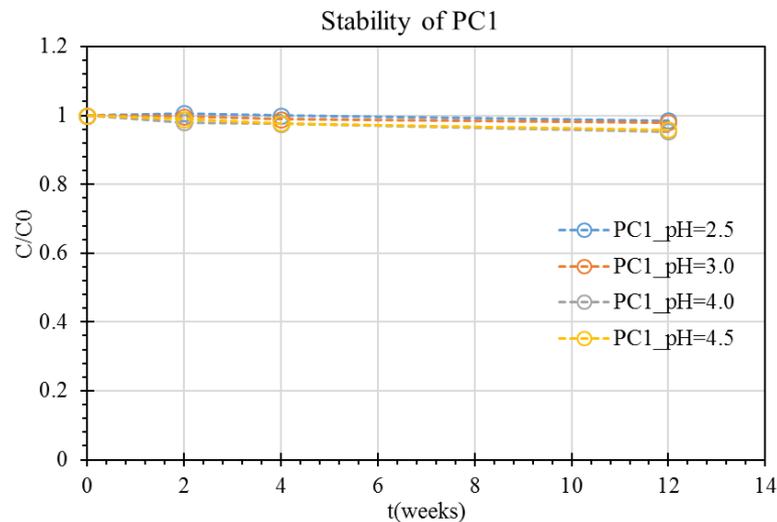
- C12-EO3-SO4Na, Polystep B330
- C13-EO3-SO4Na, Polystep B40
- C14-16-AOS, Petrostep-C1; PC1



# Stability of surfactant(pH)



- $T=35^{\circ}\text{C}$ ,  $0.2\text{M Na}_2\text{SO}_3$
- pH was adjusted by  $\text{HCOOH-NH}_4\text{HCO}_2$  buffer solution
- Three surfactant candidates are stable in simulated low pH conditions(2.5~4.5) ; without hydrolysis about 3 months





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# Solubility of surfactant in injection brine

- Brine composition

Salt	Conc(g/L)
<b>CaCl<sub>2</sub>*2H<sub>2</sub>O</b>	<b>3.2156</b>
<b>MgCl<sub>2</sub>*6H<sub>2</sub>O</b>	<b>1.1419</b>
<b>NaCl</b>	<b>72.3874</b>
<b>Na<sub>2</sub>SO<sub>4</sub></b>	<b>2.2000</b>

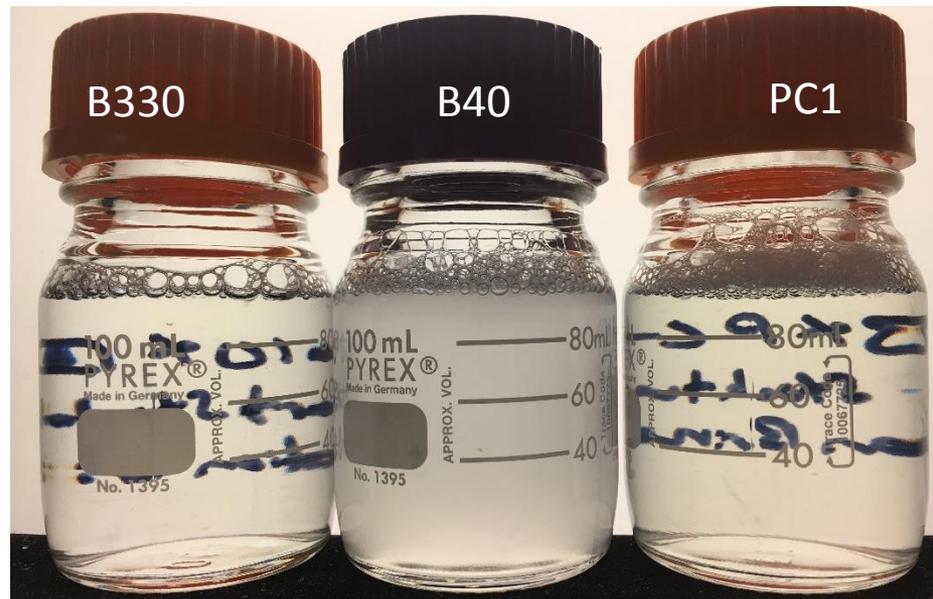
TDS: 76,061 mg/L



# Surfactant solubility in injection brine

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C12-EO3-sulfate C13-EO3-sulfate C14-16AOS



T=35°C

- B40 is cloudy, not completely soluble in injection brine
- Surfactant B330 and PC1 could be completely soluble in the injection brine



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# Properties of minerals

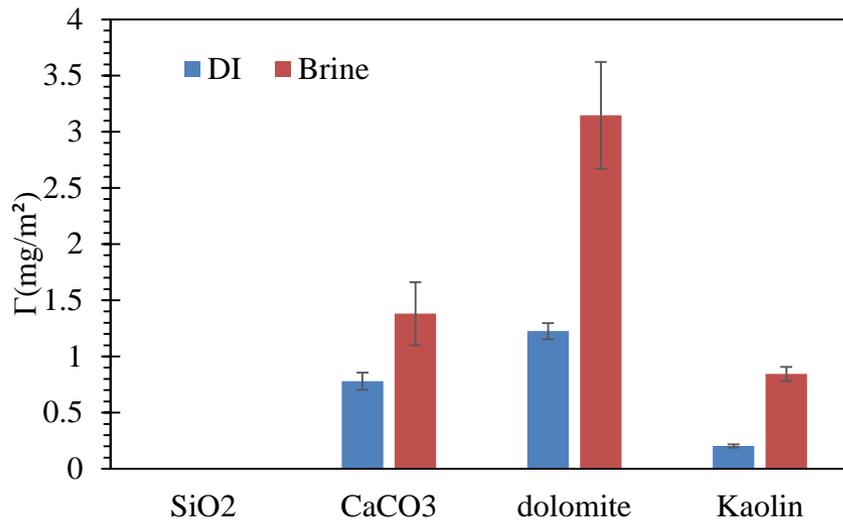
Minerals	Mass ratio of the main elements (wt%)				Zeta potential in 0.1 M NaCl (mV)	BET surface area (m <sup>2</sup> /g)
	Ca	Mg	Al	Si		
Sciencelab Dolomite	14.48±2.73	12.41±3.81	0.95±0.47	2.10±1.56	3.5±0.41	0.85
Calcite	33.39±6.53	0.84±0.55	0.00	0.00	4.4±0.68	2.12
Silica	0.00	0.00	0.00	46.67±1.95	-34.5±2.48	4.01
Kaolin	0.00	0.00	21.79±1.43	23.65±1.83	-12.9±0.90	18.63

- Minerals used are representative components in the sandstone reservoir
- Sandstone(SiO<sub>2</sub>), carbonate(calcite and dolomite), clay(kaolin)

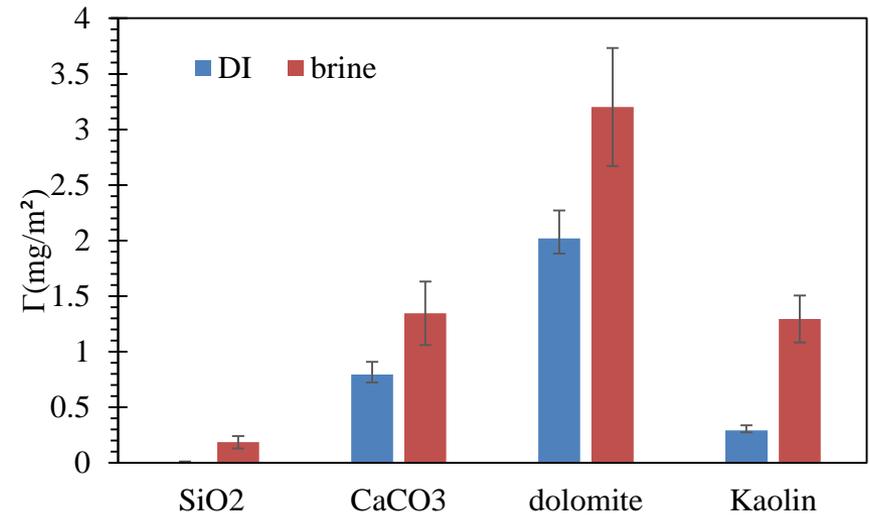


# Surfactant adsorption @35°C

Adsorption of B330 in DI and brine



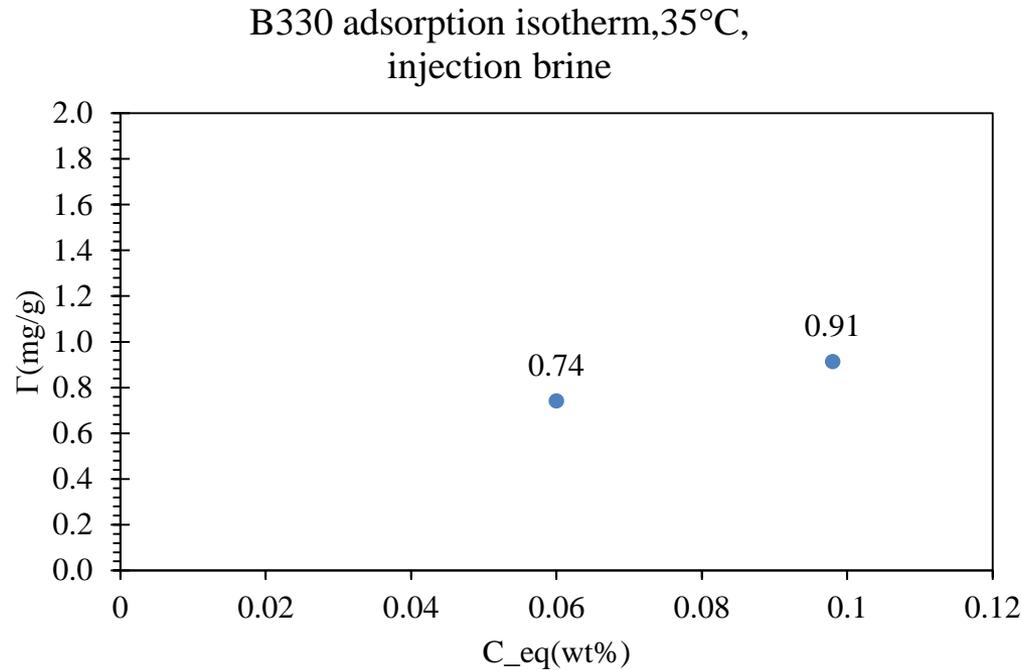
Adsorption of PC1 in DI and brine



- Both of surfactant B330 and PC1 has high adsorption on carbonate and clay
- Negligible adsorption on silica



# Adsorption on Berea sandstone, 35°C, brine



- 35°C and injection brine
- Adsorption on Berea sandstone was 0.74~0.91 mg/g



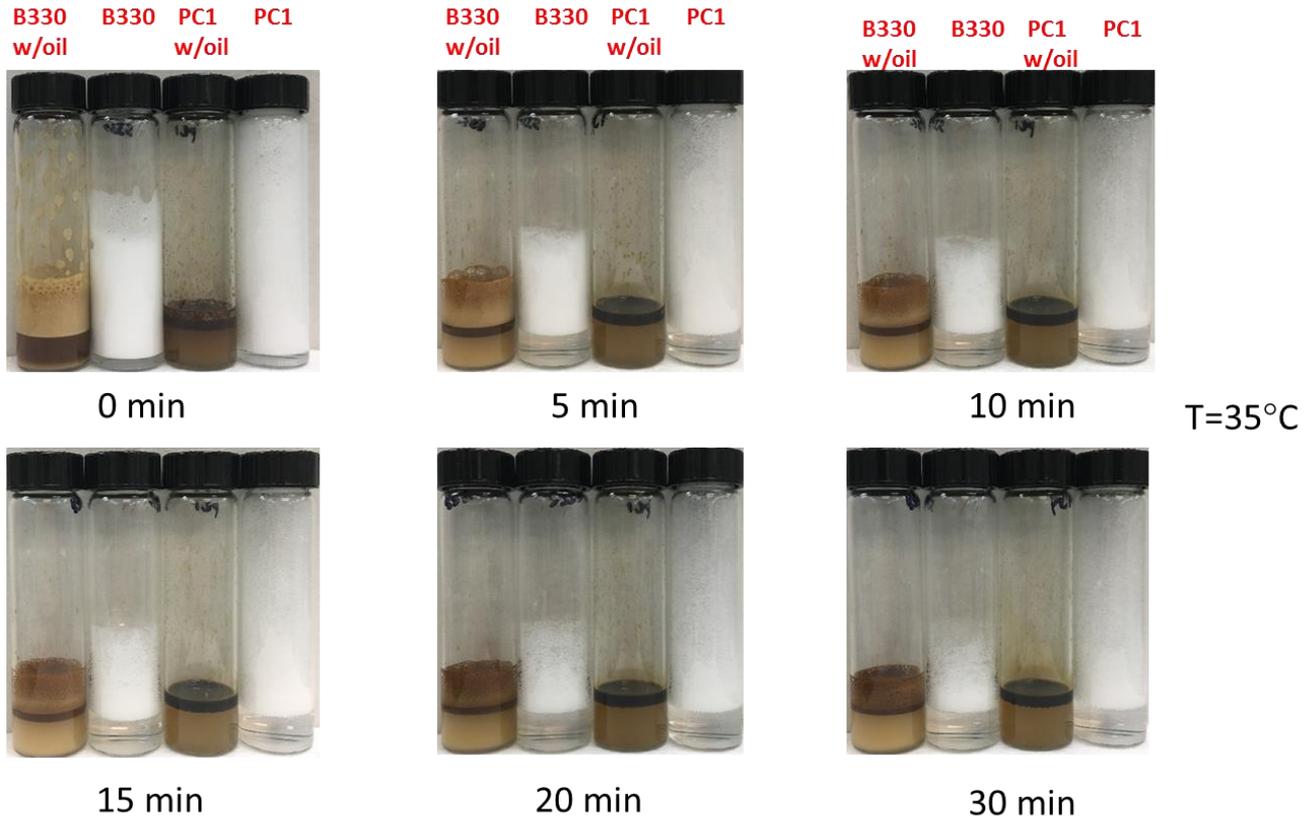
# OUTLINE

- Surfactant stability
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- **Bulk foam test and foam flood in core**



# Bulk foam/oil test B330 and PC1

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- $V_{oil}:V_{surfactant}=1:5$
- PC1(C14-16AOS) : Strong foam without oil ; no foam with oil
- B330: Strong foam without oil ; moderate foam with oil



# CO<sub>2</sub> Foam EOR in Berea Sandstone

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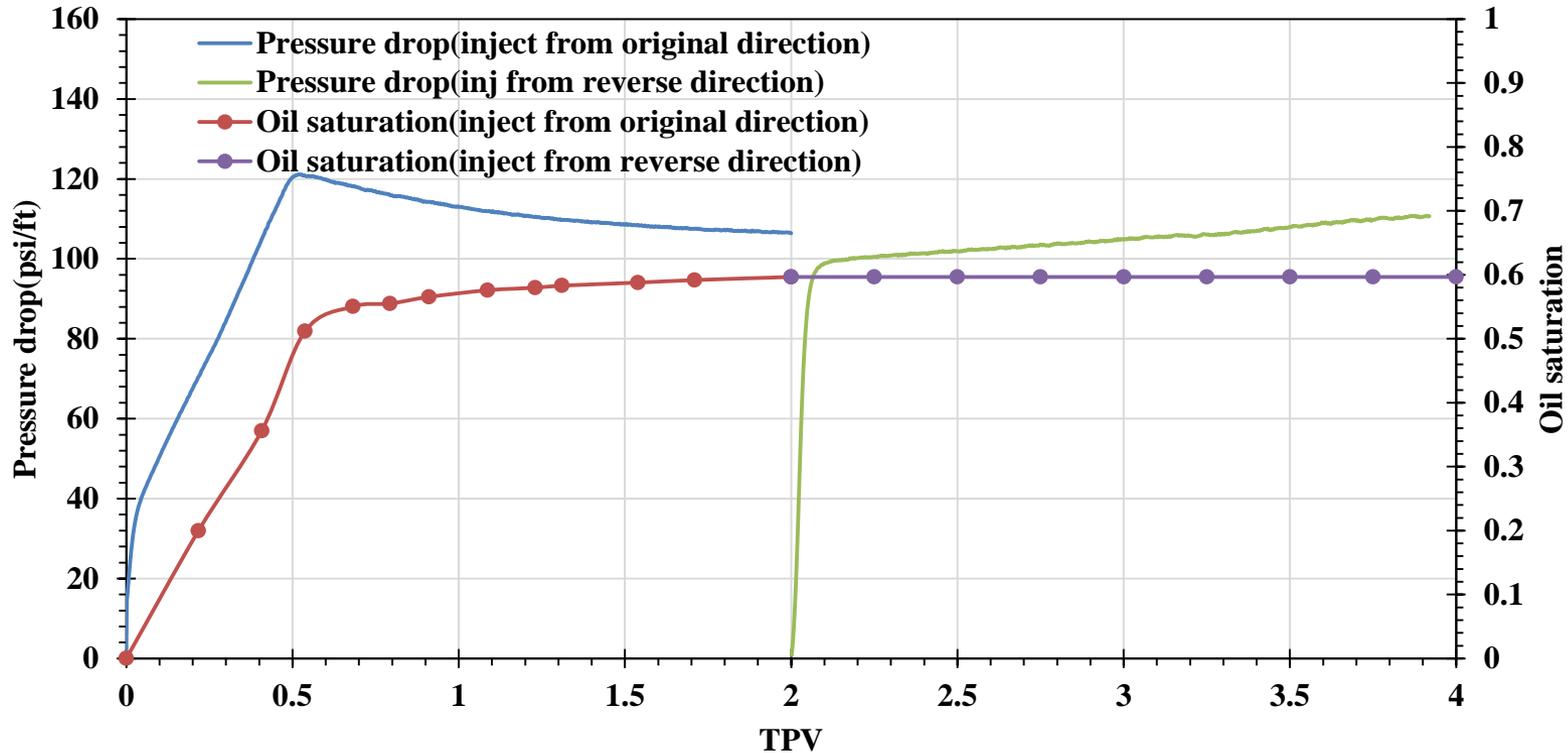
Material	Dimensions(L*D)	Permeability(mD)	Porosity (%)
Berea Sandstone	1ft*3inch	57	18.0

1. vacuum the core; [room T and 1atm]
2. water saturation; [room T and 1atm]
3. crude oil saturation; [room T and 1atm]
4. water flooding; [t=35°C,p=300psi]
5. CO<sub>2</sub> foam flooding- coinjection of CO<sub>2</sub> and surfactant with 1ft/day; 70% foam quality and 1% surfactant\_C12-EO3-SO<sub>4</sub> 2- . [T=35°C,P=300psi]



# Oil saturation

Oil saturation in Berea sandstone core,  $k=57\text{mD}$



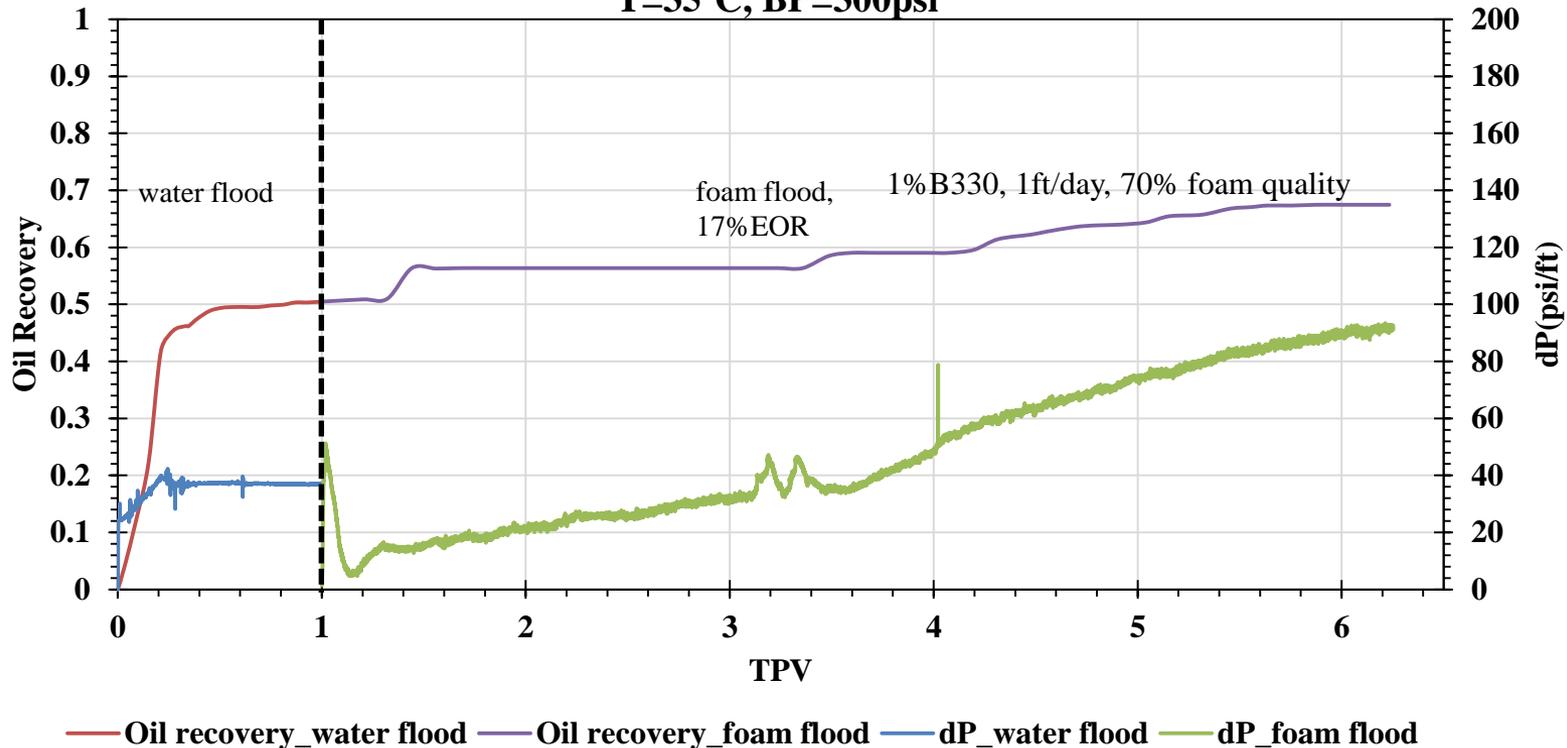
- Core was flooded with oil from both ends due to capillary end effect during oil saturation process (capillary end effect is not obvious in this case)
- **Oil saturation: 59.7%**



# Immiscible CO<sub>2</sub> Foam flood (under current reservoir P)

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Water flooding and foam flooding in Berea sandstone  
T=35°C, BP=300psi



- Oil recovery was increased by 17% by immiscible CO<sub>2</sub> foam flooding
- Pressure gradient gradually increases with decreased oil saturation during CO<sub>2</sub> foam flooding



## Conclusions:

- All three candidate surfactants are stable in low pH condition (within 3 months)
- B330 and C14-16 AOS are soluble in injection brine
- B330 has low adsorption ( $<1$  mg/g) and moderate oil tolerance
- Immiscible  $\text{CO}_2$  foam using 1% B330 could recovery 17% oil and show mobility control ability

## Future work:

- Pressurize phases ( $P > \text{MMP}$ ) and conduct miscible  $\text{CO}_2$  foam flood @  $35^\circ\text{C}$