Experimental Investigation of Polymer Adsorption-Induced Permeability Reduction in Low Permeability Reservoirs

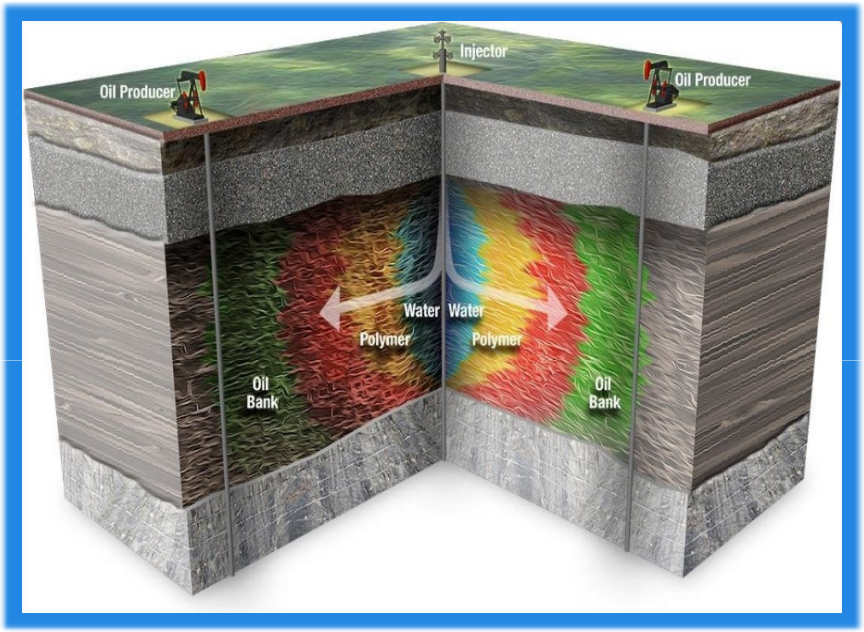
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Research Background

➢ Polymer Flooding for EOR



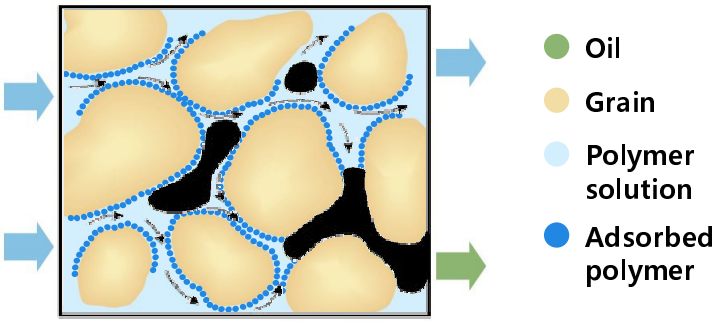
- **Polymer flooding..**
  - ✓ Nearly disappeared in 90’ due to its high costs and the access to new easy exploitable reserves, but currently it is applied solely or in combination with other EOR technique.

- **A mature technology in chemical EOR method**
  - ✓ Increasing brine viscosity improving sweep and displacement of bypassed oil from low-permeability zones
  - ✓ Reduce water production at production well

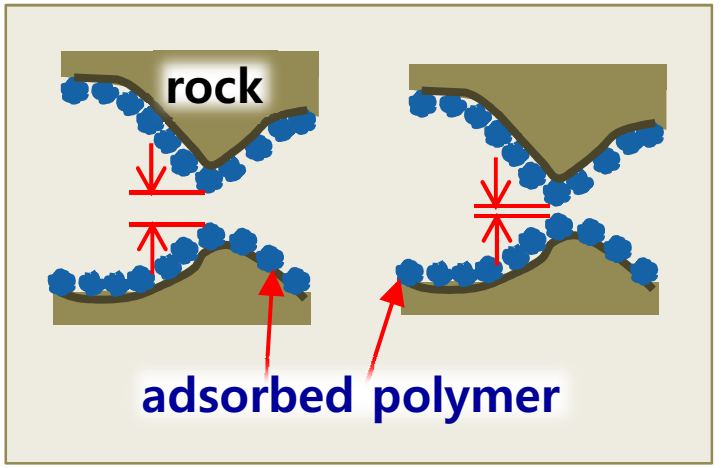
Research Background

➢ The Effect of Polymer Retention in Porous Media

- **Decrease water relative permeability**
  - ✓ Polymer retention: entrapment, adsorption
  - ✓ HPAM molecular: water-wet
  - ✓ Reduce water production and increase oil production



- **Decrease system permeability**
  - ✓ Polymer adsorption layer reduces the size of flow path
  - ✓ System permeability is reduced
  - ✓ Negative effect in polymer injectivity



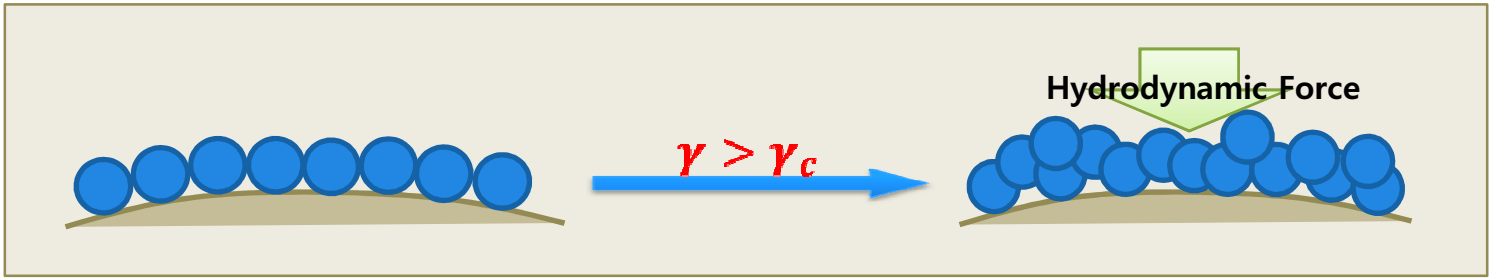
Research Background

➢ Measurement of Dynamic Polymer Adsorption

- **Zaitoun and Chauveteau, 1998**
  - ✓ **1D core flow experiments**
  - ✓ **Calculated polymer hydrodynamic adsorbed layer thickness deduced from the measurement of permeability reduction**

  ※ Limitations: Uniform fluids velocity & No viscous fingering

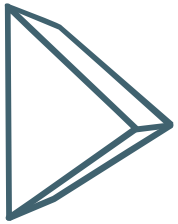
- **Chauveteau et al., 2002**
  - ✓ **Polymer adsorption layer thickness can be increased when polymer molecular flows at critical shear rate**



Research Objectives

➢ Polymer Flooding in Low Permeability System

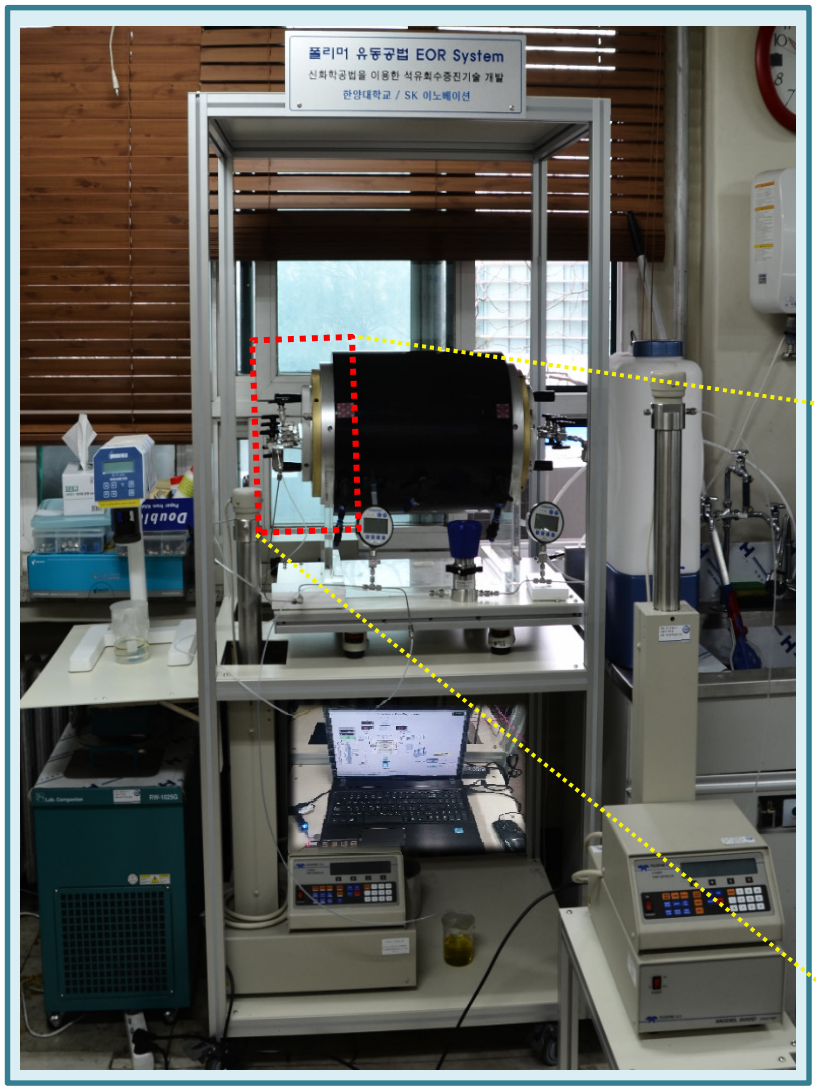
- Experiment of polymer flooding in 2D 5-spot (1/4 unit) system involves variation in fluid velocity for the locations in system
- Polymer retention during polymer flooding may enhance oil flow but, spontaneously decrease system permeability
- Particularly in low permeability system, polymer flooding may not show positive EOR effect due to the polymer adsorption.

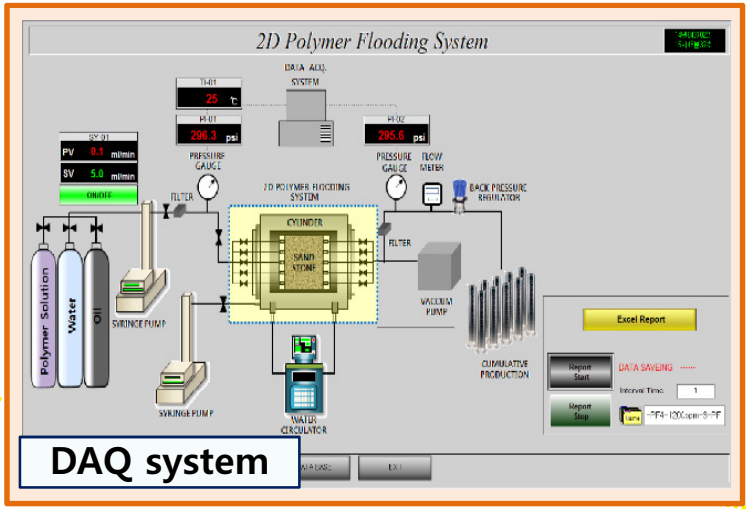


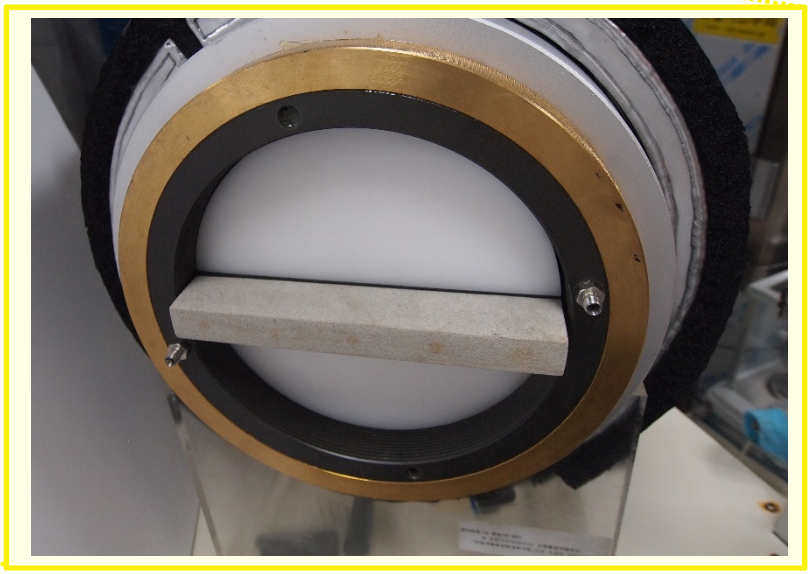
The effect of polymer concentration on adsorption-induced permeability reduction in low permeability system.

Experimental Set-up

➢ Schematic of 2D Polymer Flooding Experiment







Experimental Set-up

➢ Experimental Set-up

- Porous Material: Sister gray berea sandstone
  - Porosity: ref. range 20-22%
  - Permeability: ref. range 35-60 md
- Flowing Fluid
  - Oil: Shell Morlina S2BL 10 (12 cp at 40°C)
  - Brine: 2% salinity (83wt% NaCl & 17wt% $CaCl_2$)
  - HPAM: Flopaam 3330s (Mw 8M g/mole, SNF)

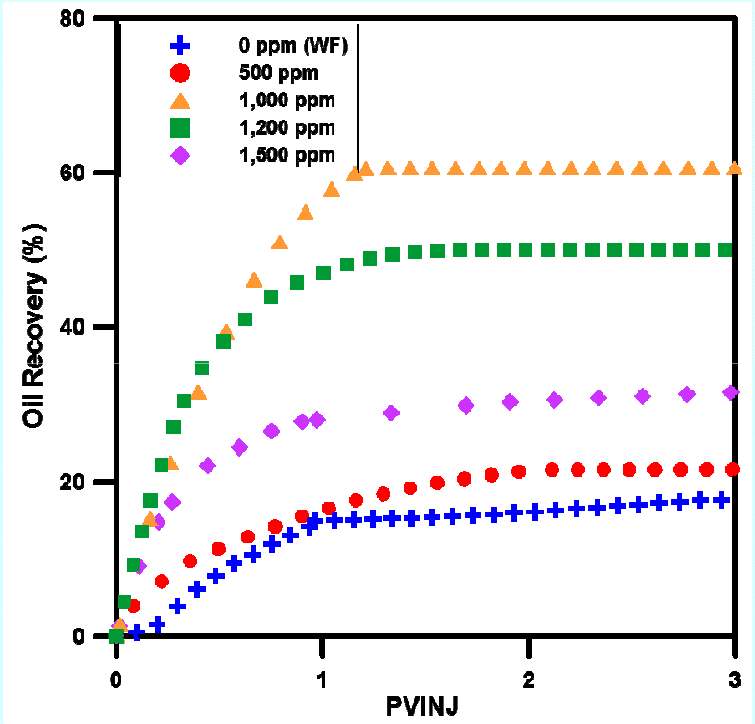
Experimental Set-up

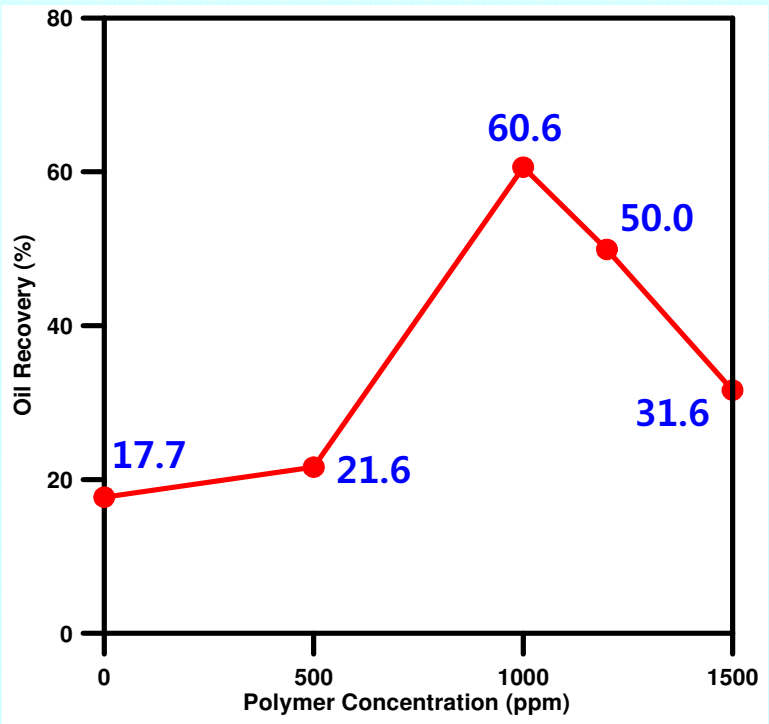
➢ Experimental Condition

Experimental Set Up					
Residual Oil Saturation	60%				
System Salinity	2% brine (83wt.% NaCl, 17wt.% $CaCl_2$)				
Polymer Concentration (ppm)	0	500	1,000	1,200	1,500
Injection Rate	0.124 ml/min (1 ft/day)				
BPR at Production	300 psig				
Total Injected Amount	3.1 PV (Till the equilibrium condition)				

Polymer Flooding Results

➢ Oil Recovery

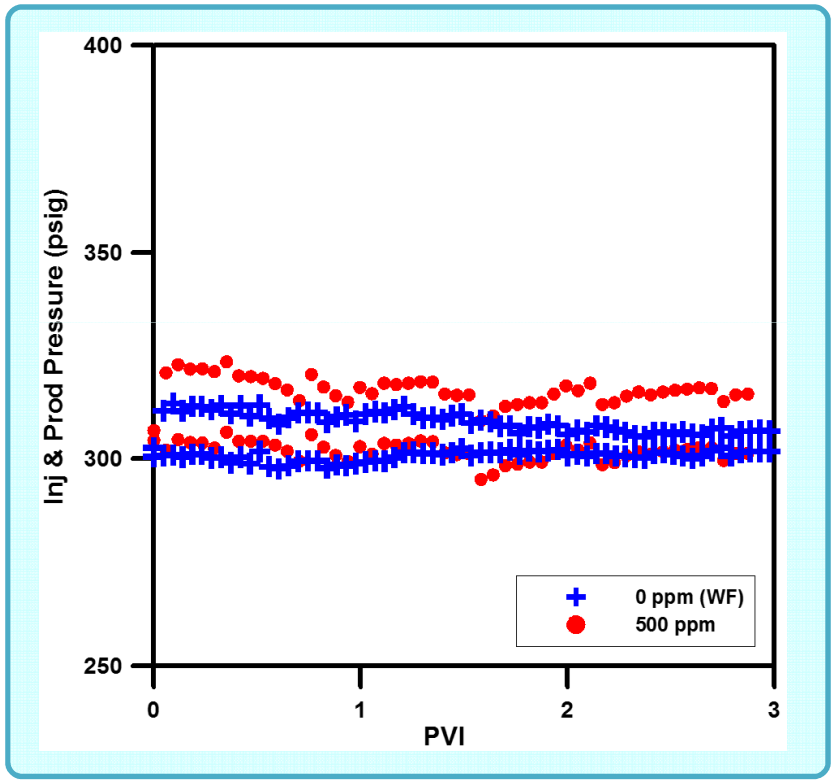


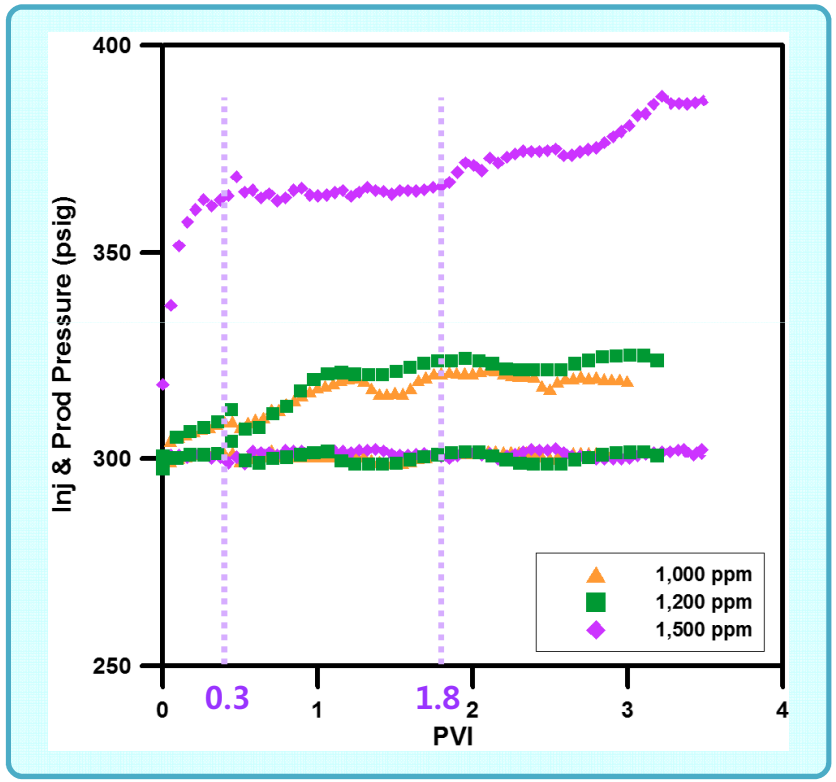


Polymer solution-oil viscosity ratio					
Conc. (ppm)	0	500	1,000	1,200	1,500
Ratio	0.06	0.19	0.23	0.35	0.62

Polymer Flooding Results

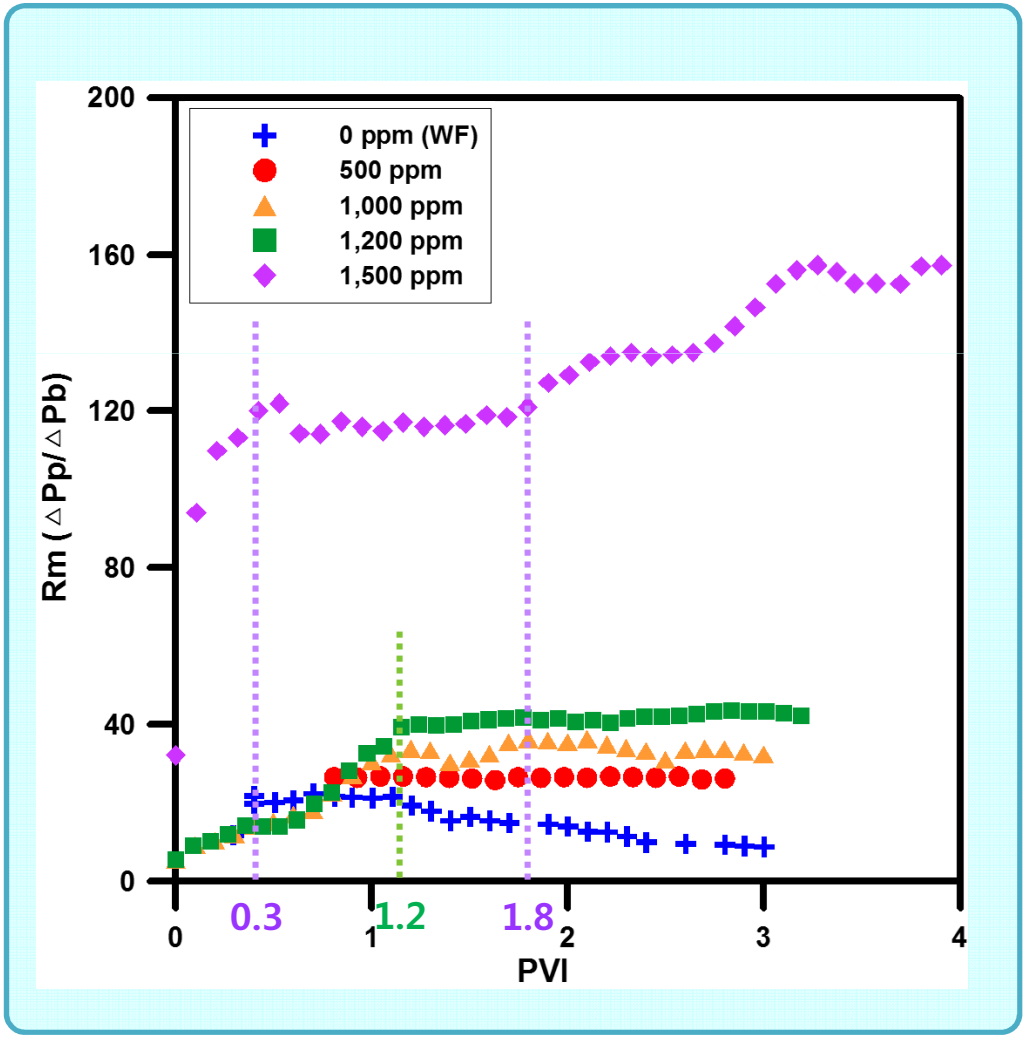
➢ Pressure Behavior at Inj. & Prod. Ports





Polymer Flooding Results

➢ Effective Permeability Reduction



- Reflection of the effect of polymer retention **(adsorption + entrapment)**

$$R_m = \frac{\Delta P_p}{\Delta P_b}$$

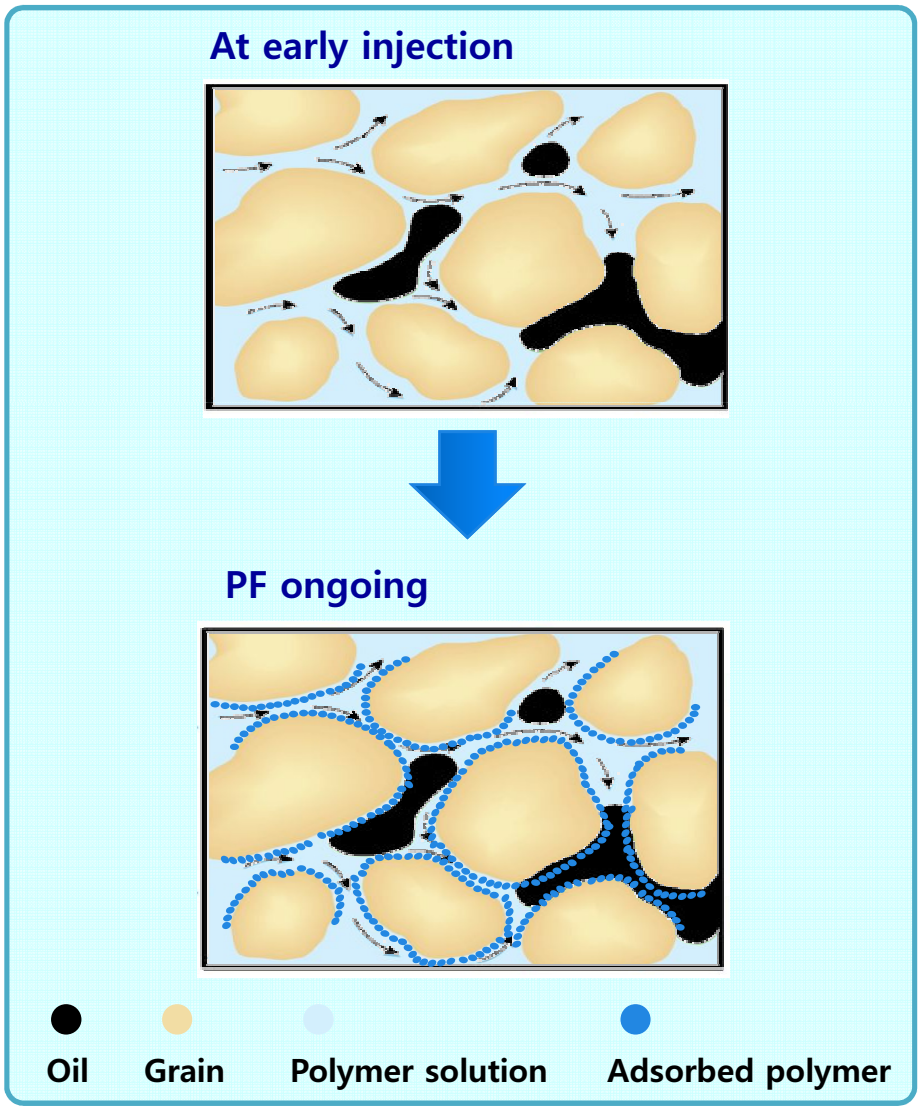
Where,

ΔP_b is pressure drop during the brine injection into clean sand slab

ΔP_p is pressure drop during the polymer flooding

Polymer Flooding Results

➢ Effective Permeability Reduction



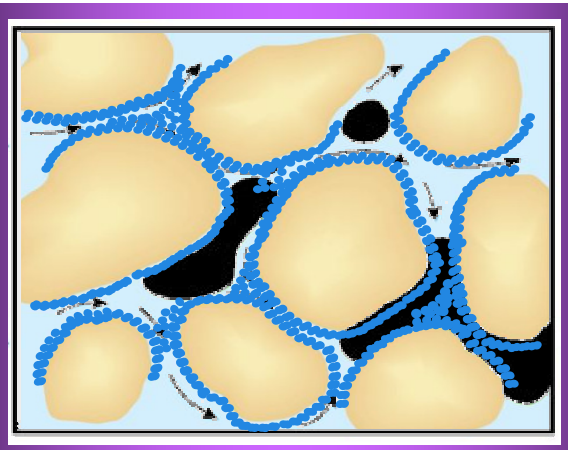
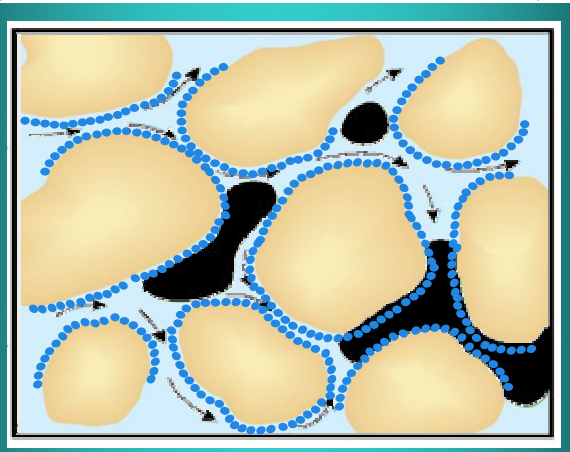
- During the **early time of injection**, polymer retention was proportional to the concentration of the solution

@ 1 PVI: Early time of injection

Conc. (ppm)	Effective Permeability Reduction (%)
0	-
500	18.5
1,000	32.4
1,200	51.0
1,500	81.6

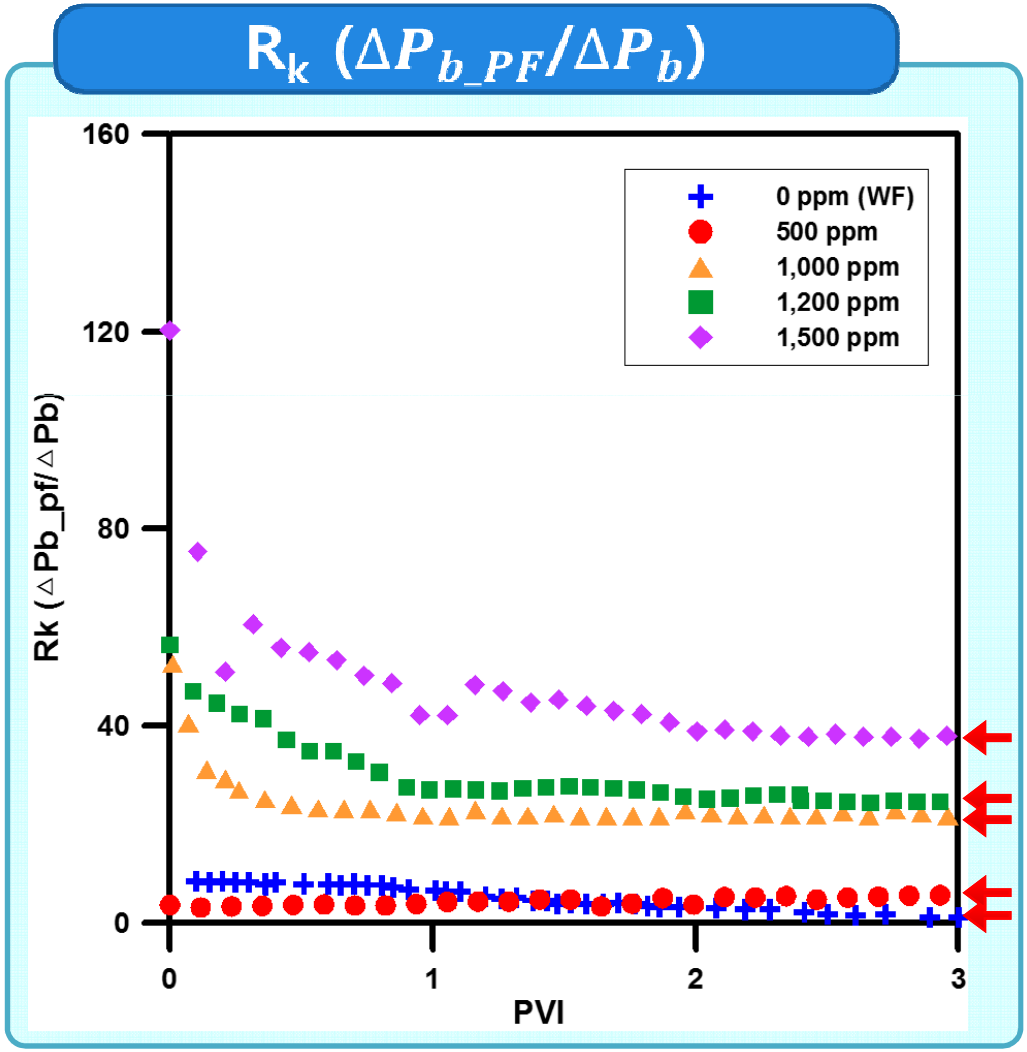
Polymer Flooding Results

➢ Brine Injection after Polymer Flooding

Polymer Flooding	Brine Injection
0 PVI → 3 PVI	3 PVI → 6 PVI
	
▪ Polymer retention (entrapment+adsorption) occurred	▪ To remove the entrapped polymer to see the effect of polymer adsorption only

Polymer Flooding Results

➢ Permeability Reduction by Polymer Adsorption



- Reflection of the effect of **only polymer adsorption**

$$R_k = \frac{\Delta P_{b_PF}}{\Delta P_b}$$

Where,

ΔP_b is pressure drop during the brine injection into clean sand slab

ΔP_{b_PF} is pressure drop during the brine injection after polymer flooding

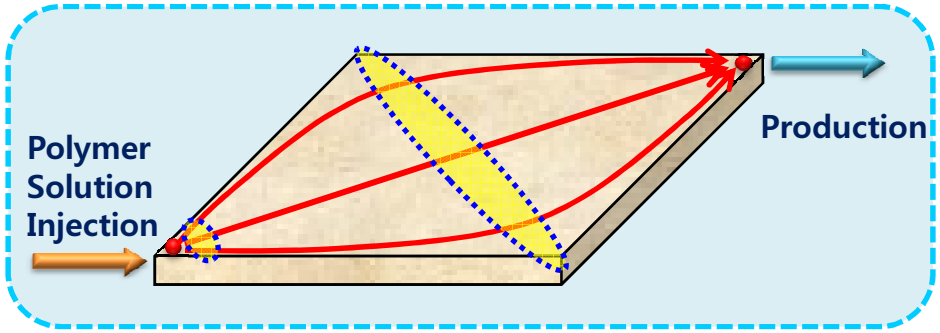
※ assumption: entrapped polymer solution is completely removed by sufficient amount of brine injection

Polymer Flooding Results

➢ Permeability Reduction by Polymer Adsorption

Conc. (ppm)	Effective Pore Radius of Clean sand (μm)	Adsorption thickness (μm)	Final Effective Pore Radius (μm)	Permeability Reduction		
				k_b (mD)	k_b' (mD)	Reduction (%)
0	4.66	-	4.66	41.2	-	-
500	5.33	1.69	3.64	51.0	4.7	90.8
1,000	5.00	2.54	2.46	42.5	2.0	95.3
1,200	5.76	2.62	3.14	45.1	1.8	95.9
1,500	5.58	3.34	2.24	56.0	1.5	97.3

Shear Rate	Interstitial Velocity	Effective Pore Radius
$\gamma = \frac{4\alpha v}{R_p}$	$v = \frac{Q}{A\emptyset(1 - S_{or})}$	$R_p = 1.15\sqrt{\frac{8\,k_b}{\emptyset}}$



Conc. (ppm)	Max. Shear Rate Near Injection		Critical Shear Rate
	Before Adsorption	After Adsorption	
1,500	65.48 s^{-1}	344.71 s^{-1}	300 s^{-1}

(Chauveteau et al., 2002)

Summary & Conclusions

➢ Polymer Flooding Experiment Results

In this study, the polymer flooding experiments were conducted to low permeability reservoir system, and the effect of polymer adsorption-induced permeability reduction on oil recovery was examined. The following conclusions were drawn:

In low permeability reservoirs, the oil recovery rather decreased without EOR effect at the polymer concentrations above optimum concentration.

The polymer retention (entrapment + adsorption) in early time of injection was proportional to the concentration of the solution.

Summary & Conclusions

➢ Polymer Flooding Experiment Results

At 1,500 ppm, the effective pore radius was clogged by up to 59.8%, accordingly, the permeability was decreased from 56 mD to 1.5 mD which was 97.3% reduction.

The reason for especially large reduction in permeability in case of a high concentration is that the maximum shear rate exceeded critical rate which yielded polymer molecules additionally adsorbed on to the mono-layer of adsorption, and the thickness of the adsorption layers increased.

Consequently, it was verified that the appropriate injection concentration was important in the application of polymer injection technique to the low permeability systems.

Thank you!

Q&A