RPSEA Contract No: 07123-02

Preformed Particle Gel (PPG) for Conformance Control

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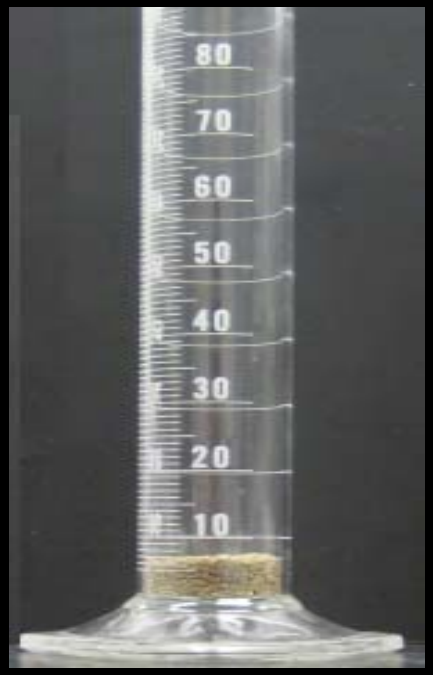
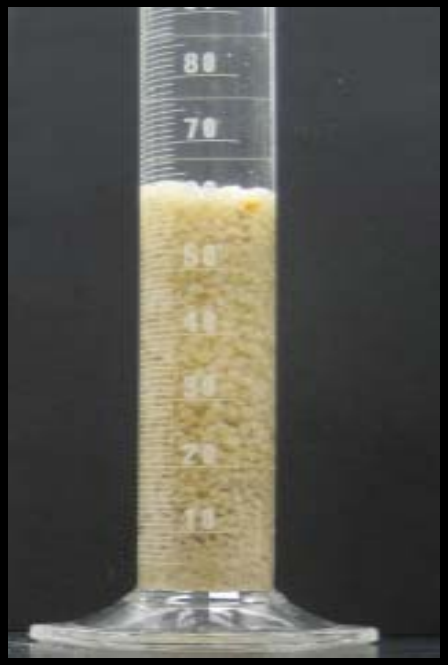
Outline

- Background
- Objective and Tasks of the RPSEA PPG Project
- Major Contributions
- Conclusions
- Acknowledgement

Background

What is Preformed Particle Gel (PPG)

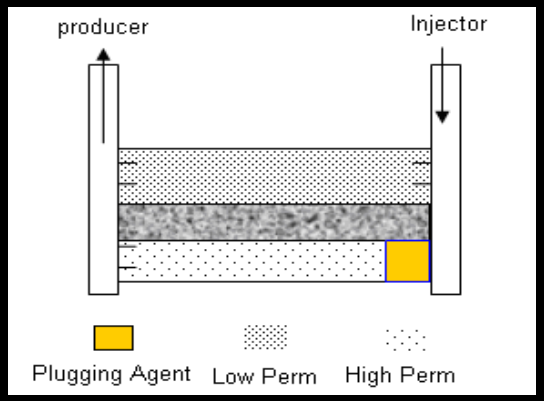


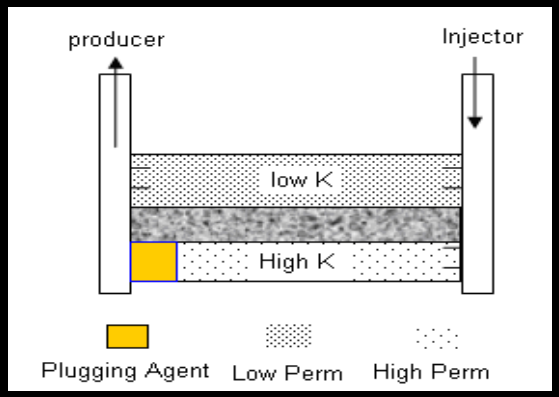


Cross-linked polyacrylamide powder

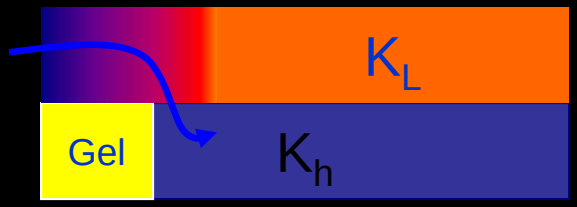
Gel Treatment to Block/Reduce Water Flow through High Permeability Zone/Streak

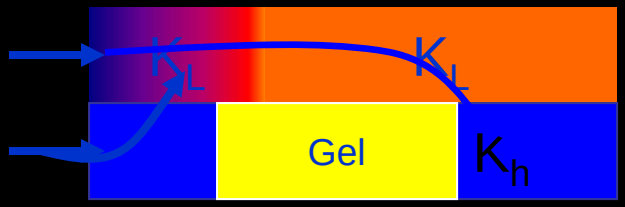
Near Wellbore Treatment (no crossflow)





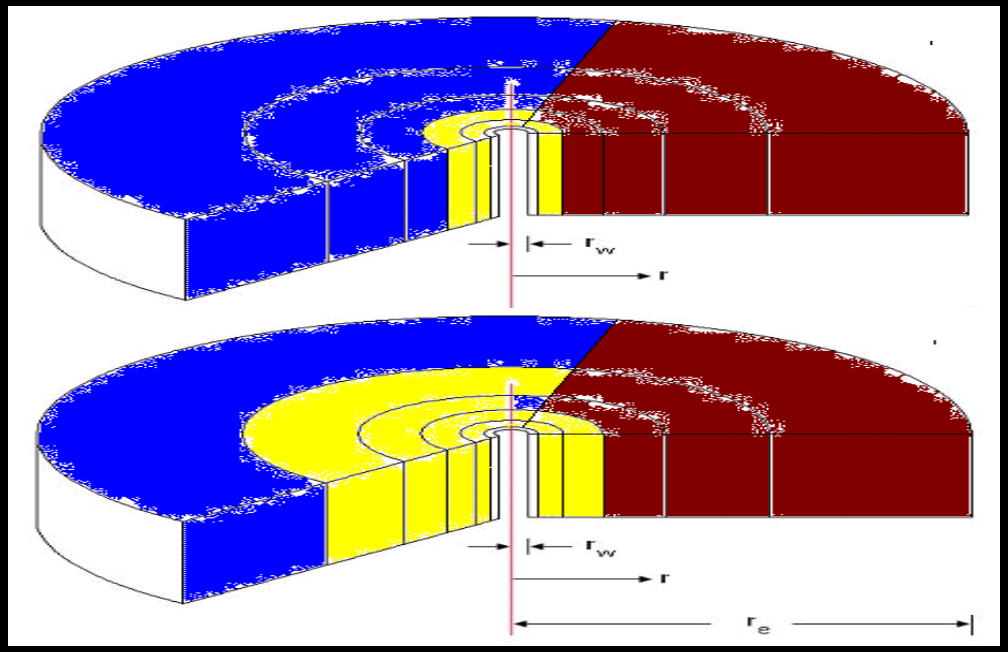
In-depth Gel Treatment (thick heterogenous layer with crossflow)





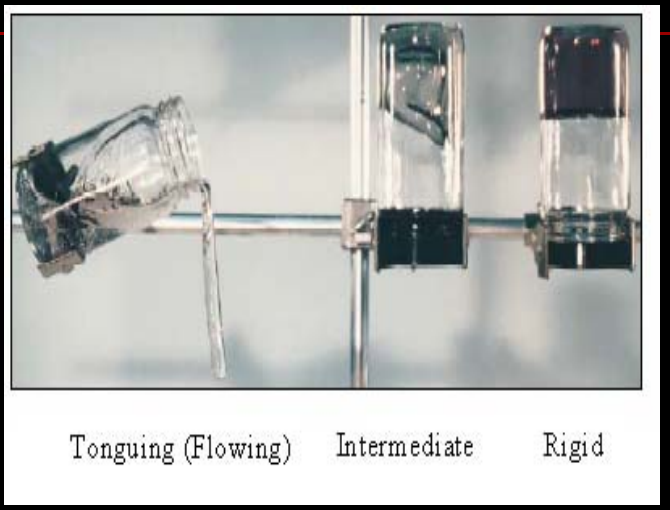
Gel Treatment to Block/Reduce Water Flow through High Permeability Zone/Streak

Areal Heterogeneity



Gels Used for Conformance Control

- In-situ gel systems: Gelant is injected into formation and gel is formed under reservoir conditions after placement. Gelation occurs in the reservoir.



- Preformed gel systems: gel is formed in surface facilities before injection, then gel is injected into reservoirs. No gelation occurs in reservoir.

A Newer Trend in Gel Treatment is Using Preformed Gels

- **Inherent disadvantages of In-Situ Gel**
  - Crosslinking reactions are strongly affected by
    - Shear by pump, wellbore and porous media
    - Adsorption and chromatography of chemical compositions
    - Dilution of formation water
- **Possible damage on unswept low permeability oil zone of in-situ gel**

Current Preformed Particle Gel Systems

- **Micro Particle Gel: μm-sized particle by Zaitoun et al/IFP. About 10 treatments in gas storage wells**
- **Bright Water®: Nano particle by Chevron, BP and Nalco Ten plus well pilot tests.**
- **Preformed Particle Gel: μm to mm-sized Grained particle, Bai et al, more than 2,000 treatments**

Objectives of the RPSEA Project

- This project will address the problems that have inhibited wide-spread application of the technique in the USA. Successful development from this project will:
- To tell where particle gels can be best used and how to optimize a PPG treatment.
- To provide improved methods to enhance particle gel treatments
- To provide a series of commercially available PPG products.
- To promote the deployment of optimized PPG technology for small producers .

Tasks of the RPSEA Project

Task 4: Summary and Analysis of PPG Field Application Results

Task 5:Quantify particle gel transport through fractures and fracture-like channels

Task 6: Novel Methods

Task 7: Customized PPG Products

Task 4: Field Applications

Objective: To identify where particle gels can be effective and determine how to best use them.

PPG Applications in China Oilfields

Daqing: Relative Homogenous
temperature: ~40 ºC

Dagang: Serious Heterogeneity
Temperature: 60~100 ºC

Zhongyuan: High Temperature, High Salinity.

Shengli: Serious Channels or Voids from Sand Production

Jilin: Low Permeability Naturally Fractured Reservoirs
Temperature: 20~60 ºC
Formation Brine Salinity: ~4,000 ppm

Applications:

- Water flooded mature areas
- PPG amounts: 1,000~20, 000 lbs/well
- Injection duration: a few hours to a month
- PPG or PPG combined with polymer gel

Field Application Example in China

First Pilot in Daqing, PetroChina

- Well No and Location: X7-2-F24
- Formation brine salinity: 4,500 mg/L
- Temperature: 40 ºC
- Reservoir type: Sandstone without natural fractures or intended hydraulic fractures
- Permeability: Recorded maximum permeability is 1, 200 md.

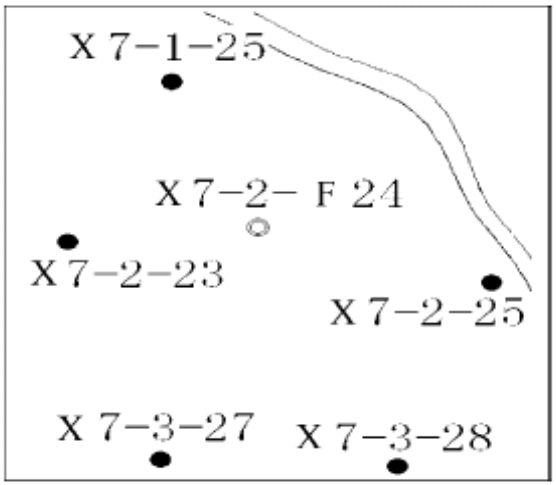
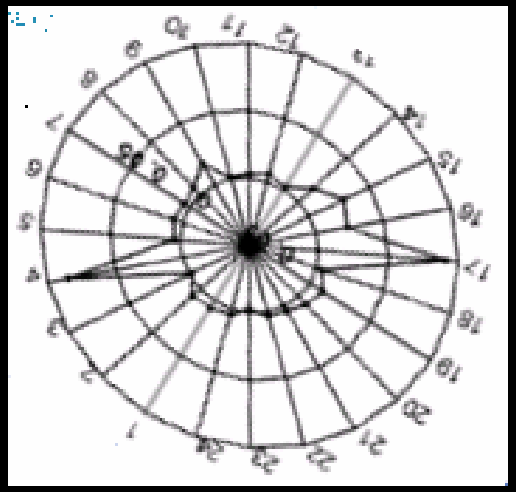


Fig. 2—Well location of the X7-2-F24 well group.

First Pilot in Daqing (Con't)

- **Reservoir Heterogeneity**
  - Vertical Heterogeneity (Injection profile): only 1/5 perforated zone absorbed water
  - Areal Heterogeneity:



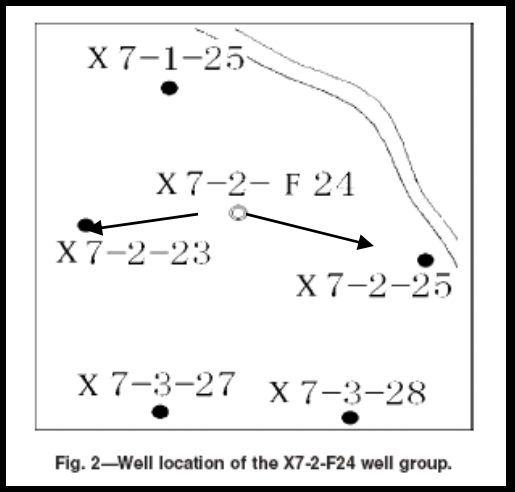


Fig. 2—Well location of the X7-2-F24 well group.

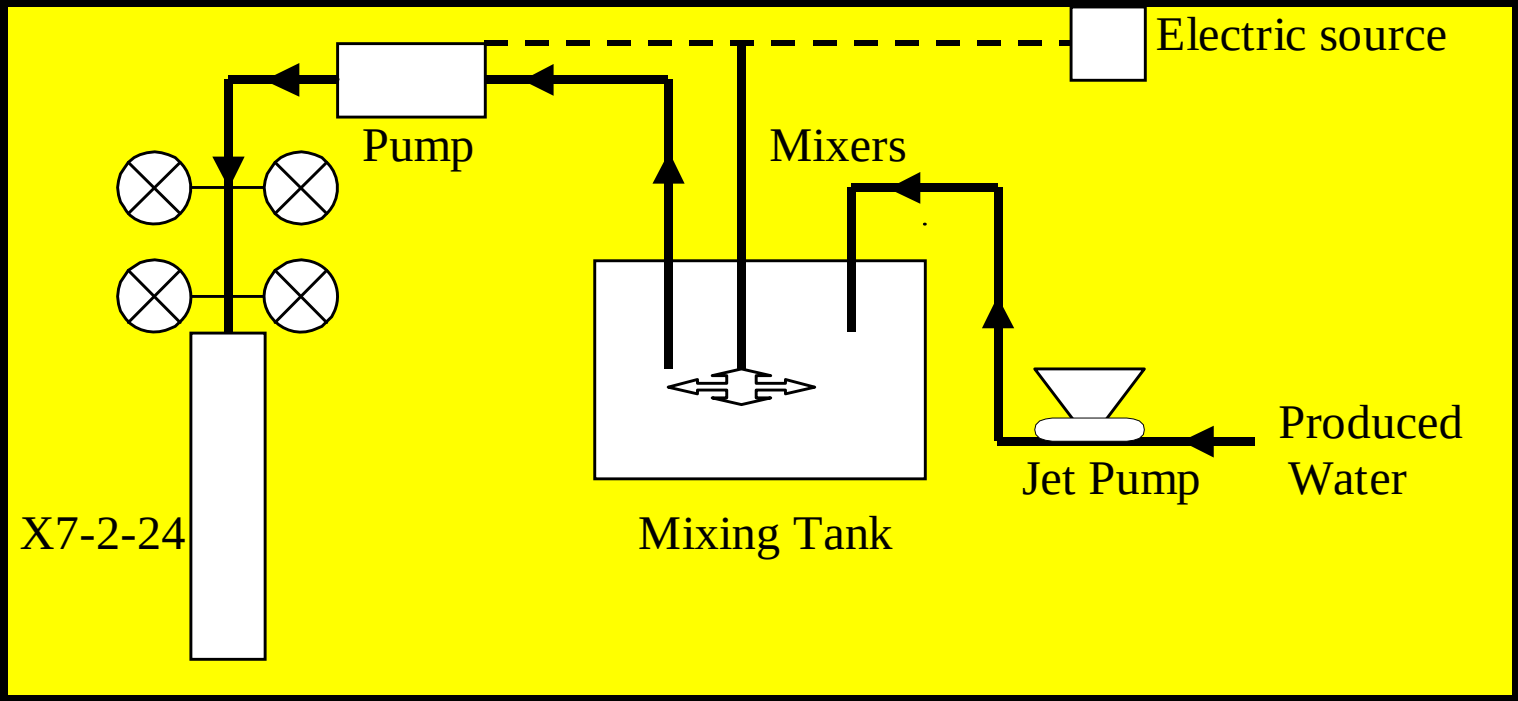
Interwell Potential Measurement

First Pilot in Daqing (Con't)

- Treatment
  - PPG amounts: 34, 100 lbs
  - PPG suspension: 3,000 m^3 PPG suspension using produced water
  - PPG Properties:
    - Size: 1.5 mm, 3 mm, and 5 mm
    - Swelling ratio: 60~80 times
    - Stability: no dehydration within 2 years
  - Injection method: PPG Suspension alternated with produced water

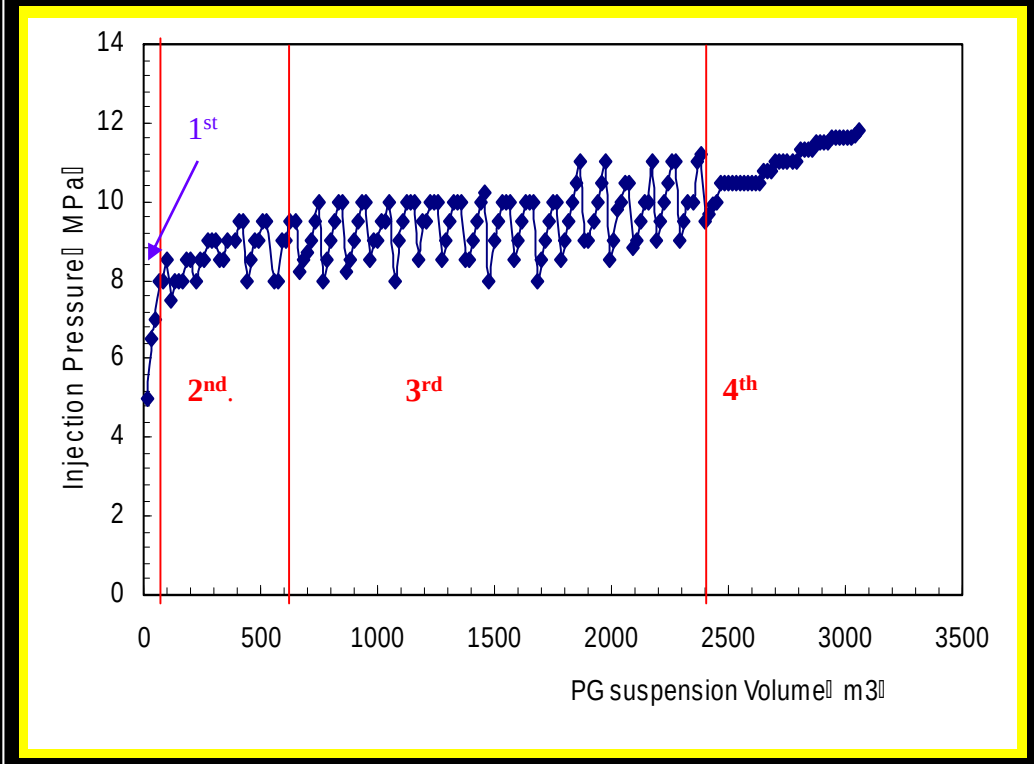
First Pilot in Daqing (Con't)

Injection scheme (facilities)



First Pilot in Daqing (Con't)

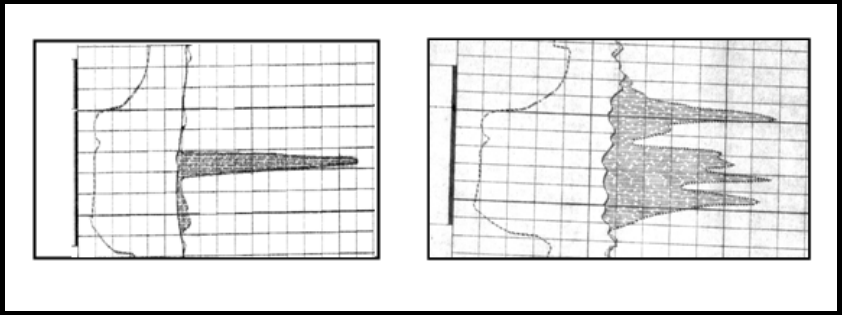
Injection performance– multiple stages



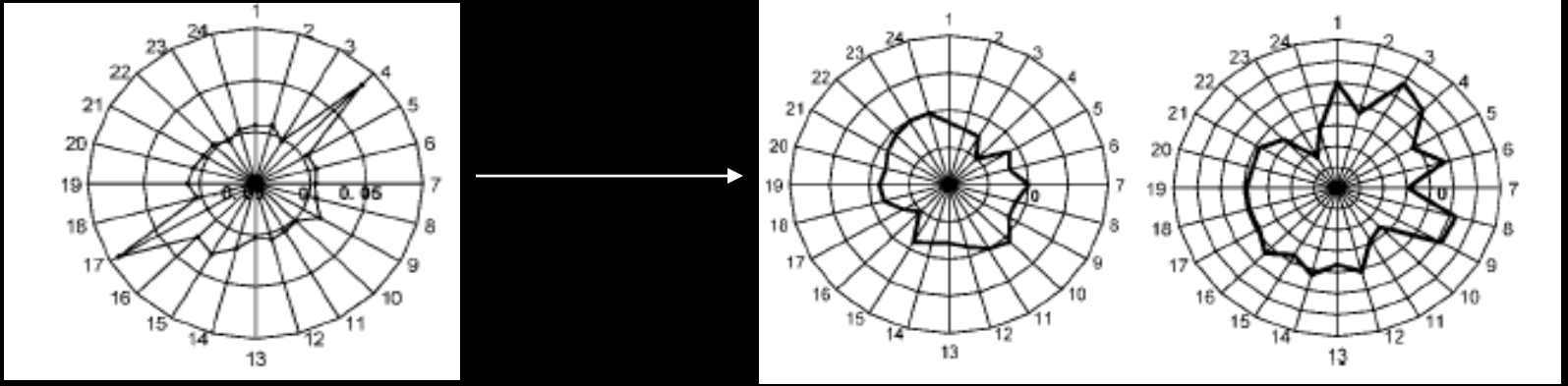
	Conc. (%)	Size (mm)	Vol (m^3)
1st	1.0	5	100
2nd	0.5	1.5	600
3rd	0.5	3	1700
4th	0.5	5	600

Results from First Pilot in Daqing

- Water injection pressure: increased from 5.0 t0 8.2 MPa
- Oil production: 17,500 bbl of increased Oil within 7 months
- Injection profile: Water absorption zone thickness from 11.5 m to 21.5 m



- Areal heterogeneity:

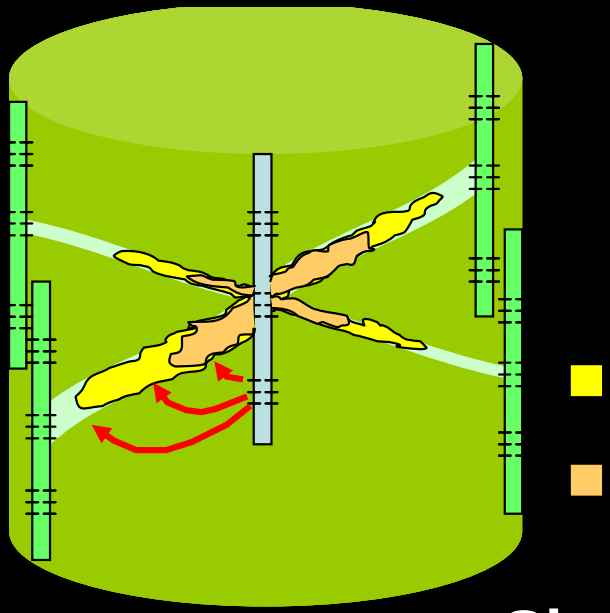


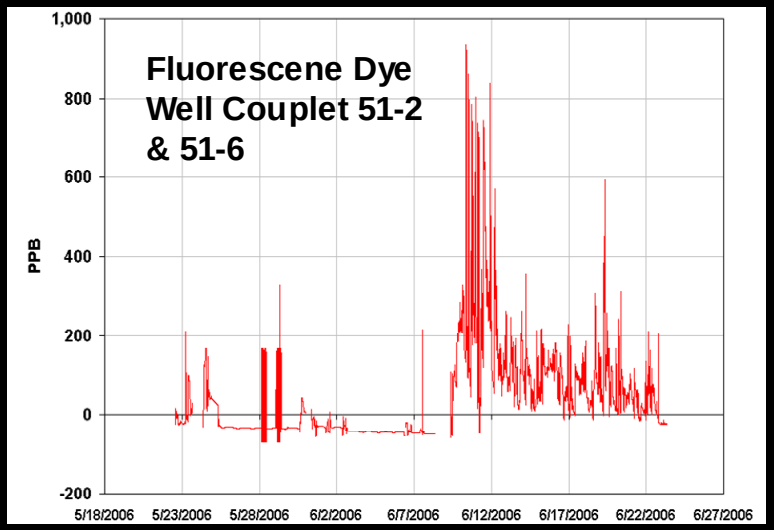
Before Treatment

After Treatment

Applications in the USA

- Remediate Unwanted Communication in a CO_2 Flooding Reservoir By Kinder-Morgan---Carbonate Reservoir

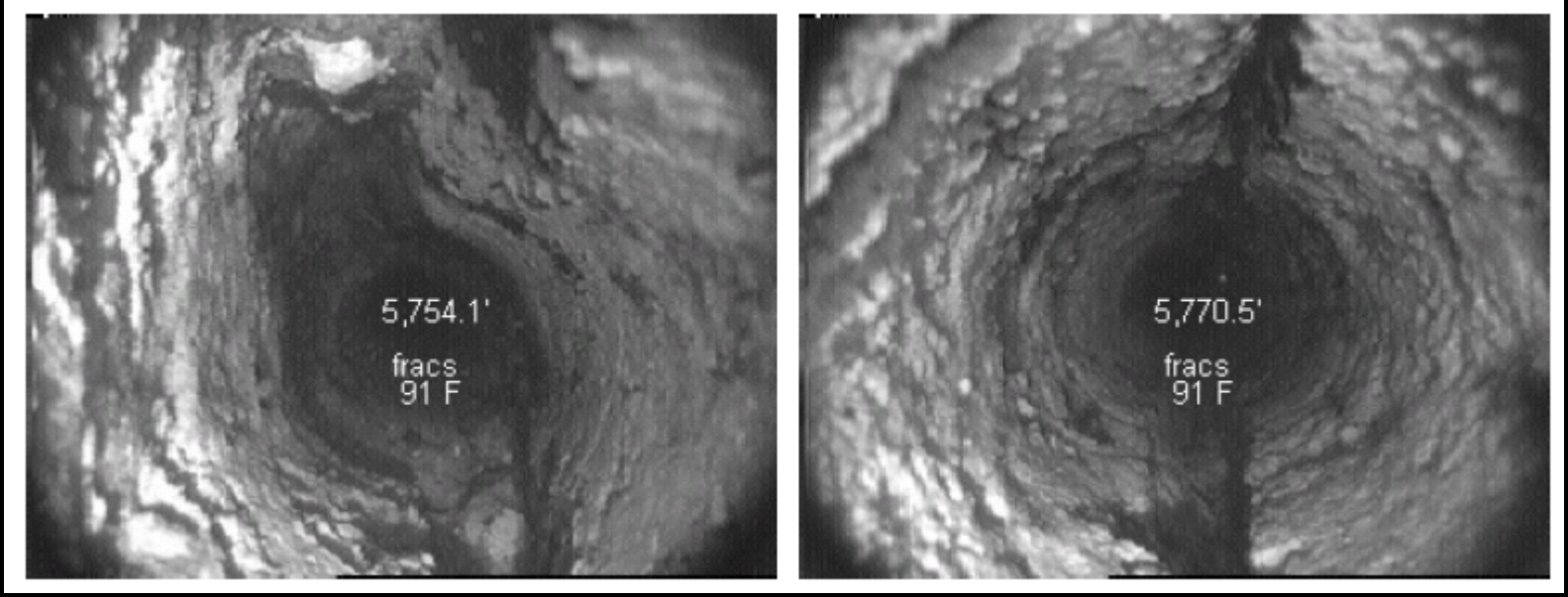




Short Circuit

Applications in the USA

Plug Void Conduit in Anton Irish Field by Occidental---CO_2 Flooding carbonate Reservoir



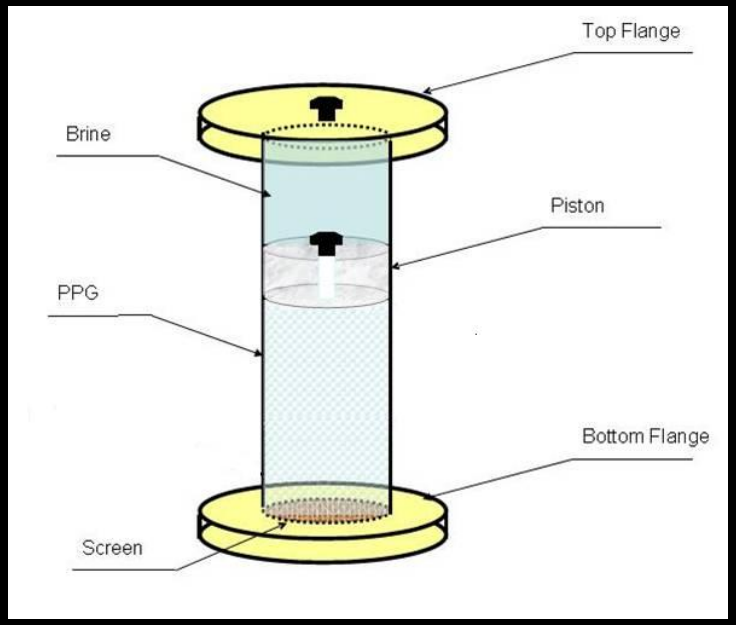
Summary of Field Application Results

- **PPG Conformance Control Technology has been successfully applied in：**
  - Mature reservoirs without natural fractures or intentionally hydraulic fractures
  - Fracture reservoirs
  - High temperature high salinity reservoir
  - CO_2 Flooding Reservoirs
  - Polymer Flooding Reservoirs
- **The injection of low concentration PPG is the key for a successful PPG treatment.**
- **Negative effect was rarely found.**

Task 5:Quantify particle gel transport through fractures and fracture-like channels

Objective: To quantify particle gel propagation and dehydration during extrusion through fractures and fracture-like channels and identify the best particle gels for different formations.

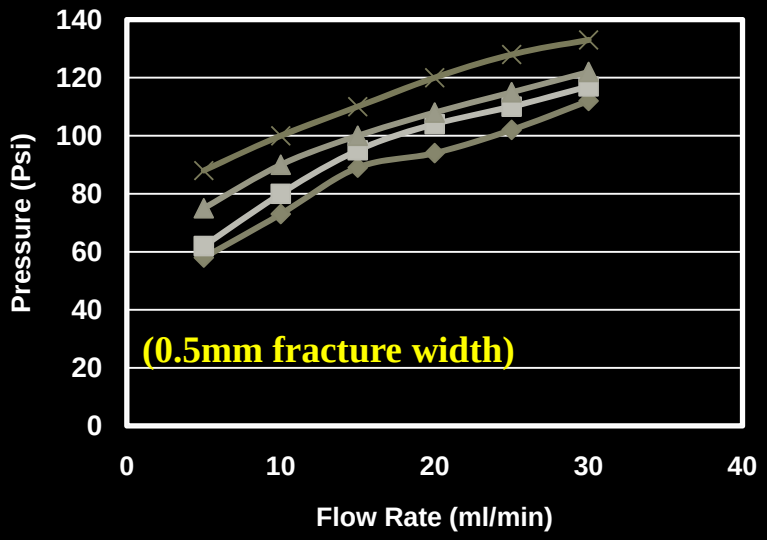
Screen and Transparent Model to Simulate PPG Flow through High-K Channels and Fractures

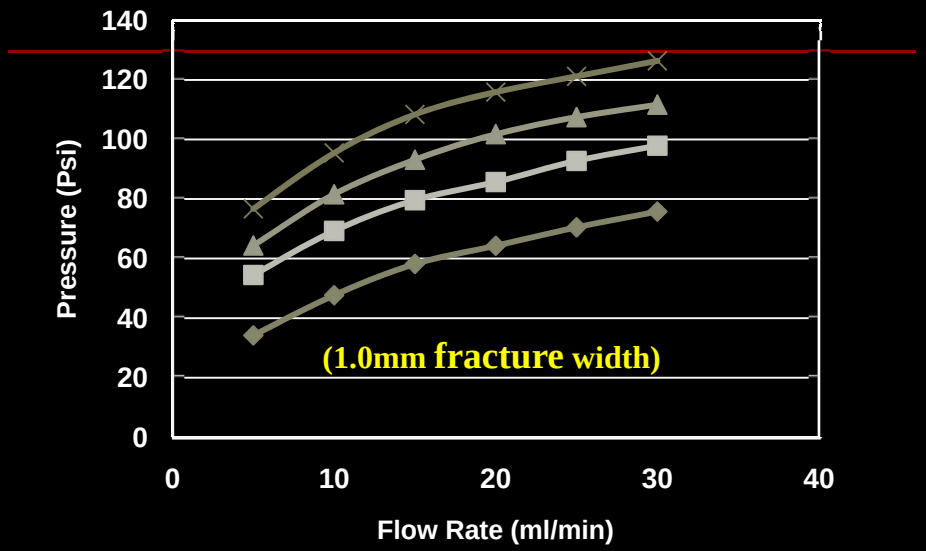


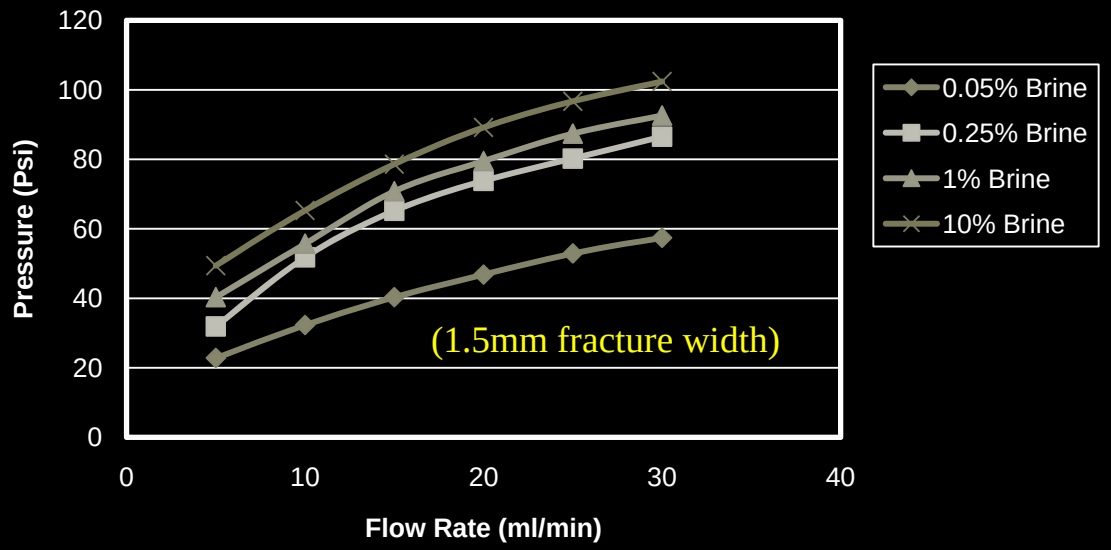
Screen Model

Transparent Fracture Model

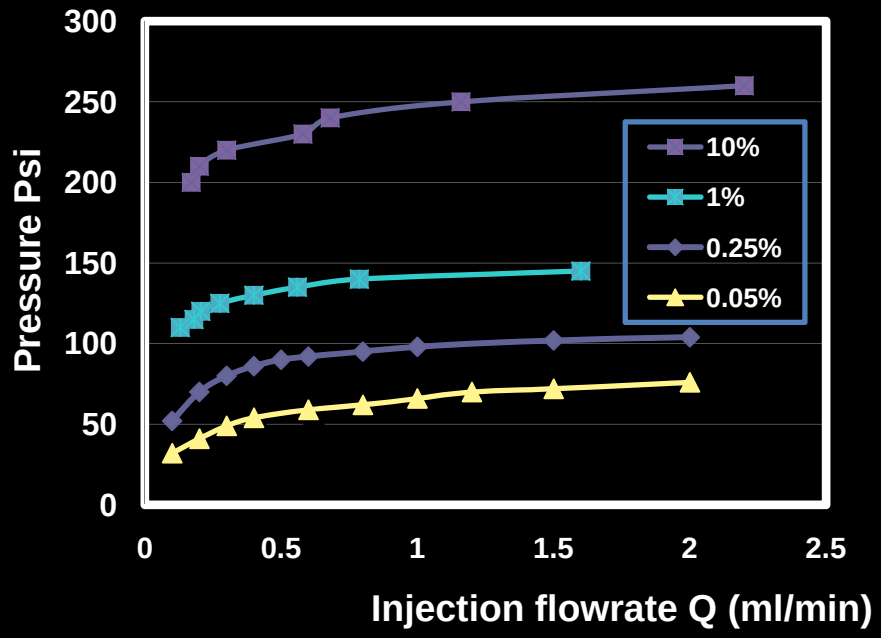
Injection Pressure as a function of Flow Rate, Brine Concentration and Fracture Width



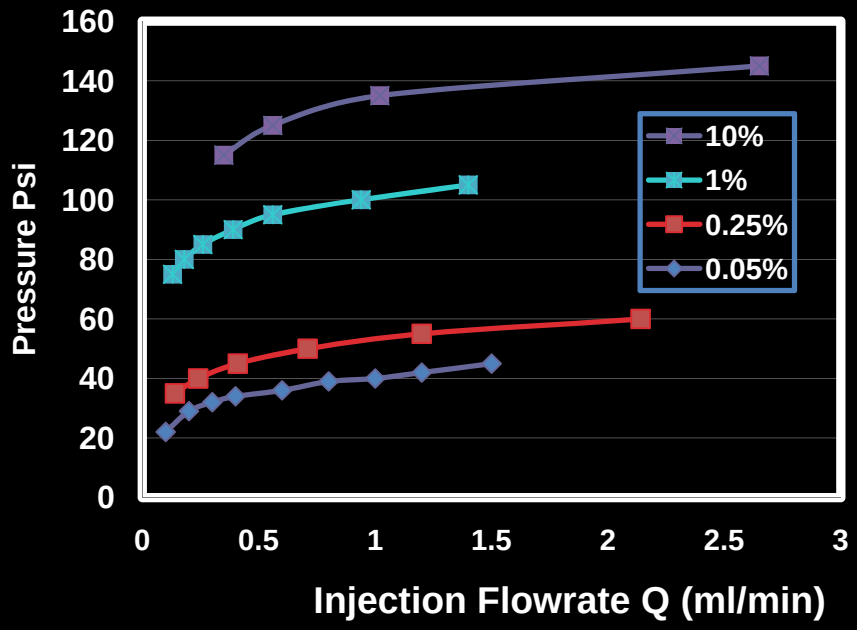




Screen Experiment Provides a Fast-Method to Select PPG



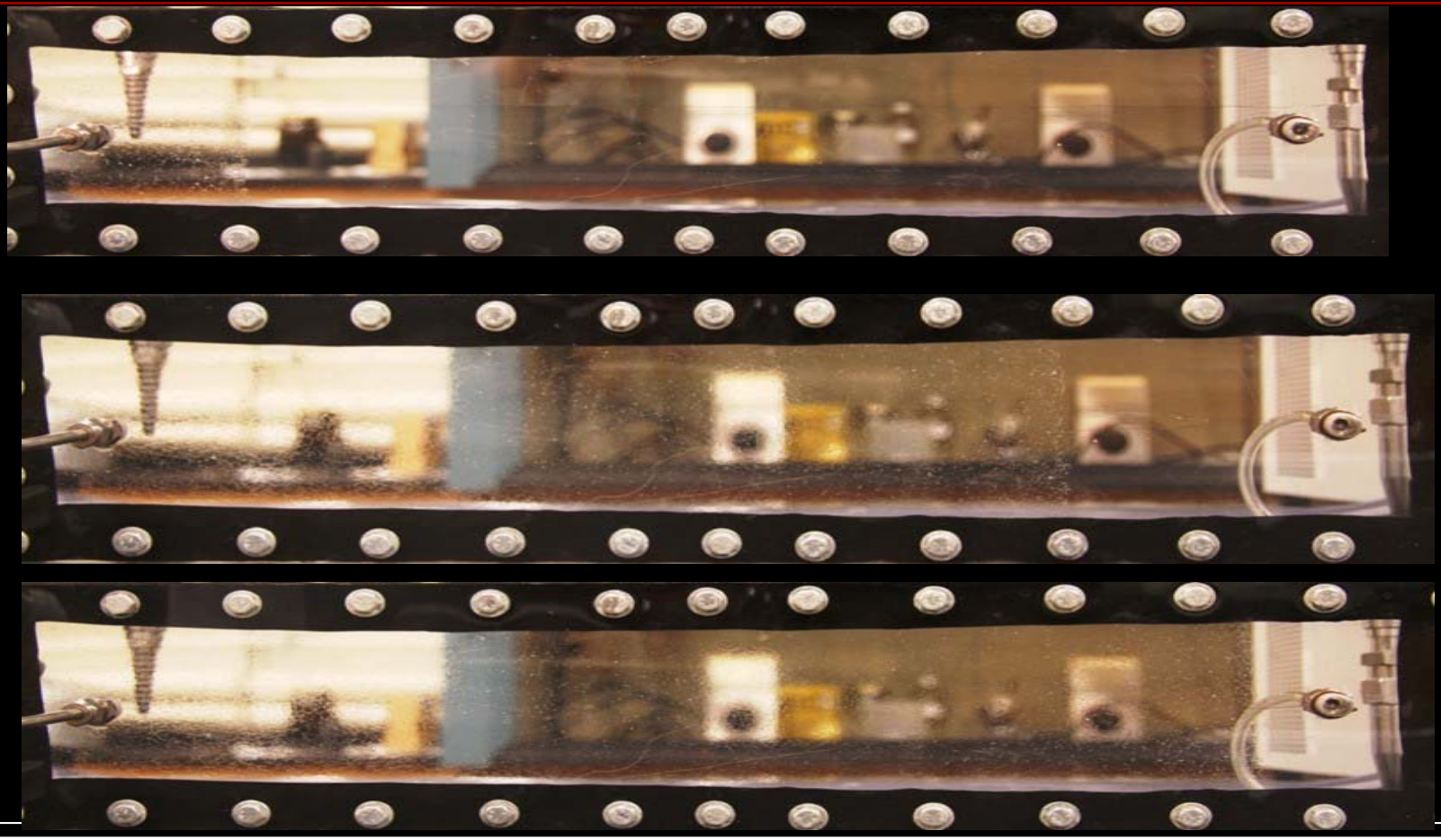
150 Mesh (0.0041 Inch)



40 Mesh (0.012 Inch)

Particle Movement and Placement in Fracture can be Visualized by Transparent Fracture Model

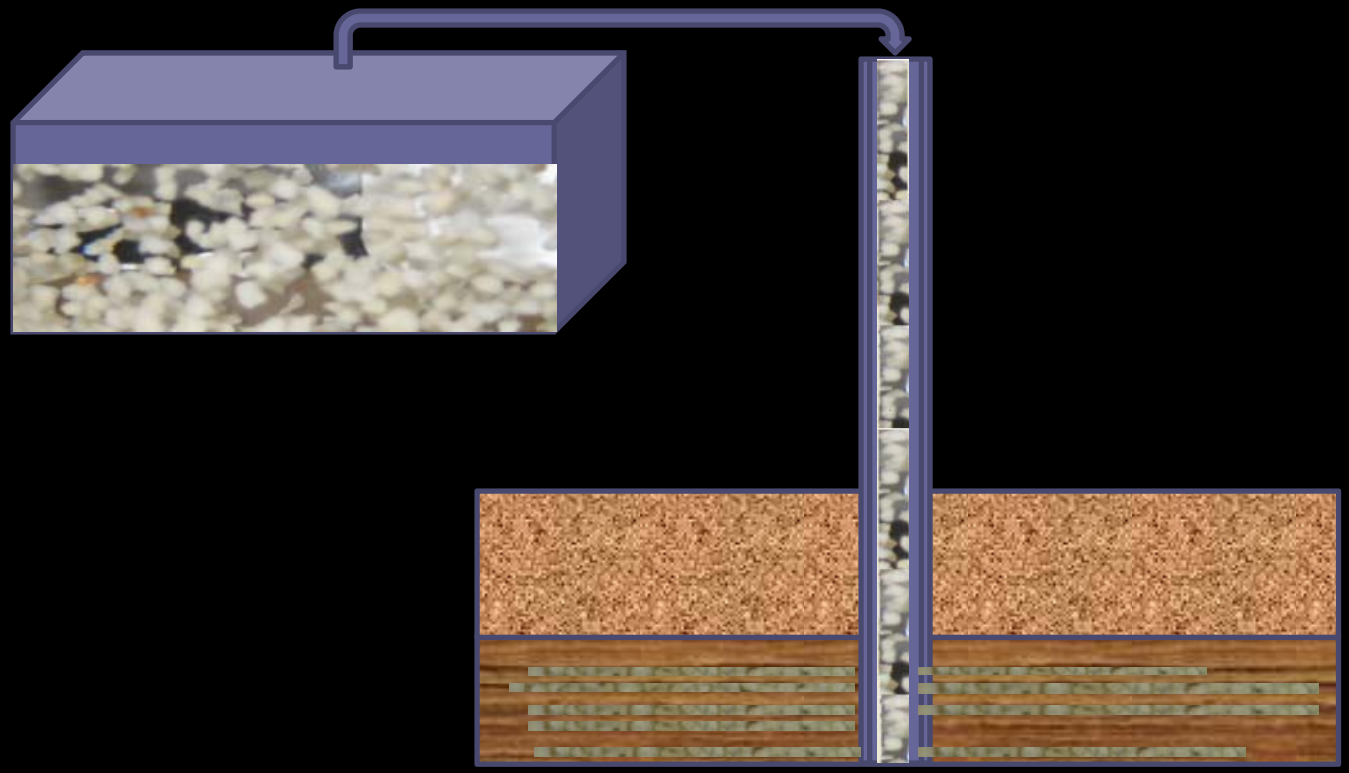
- Injecting Gel into fracture



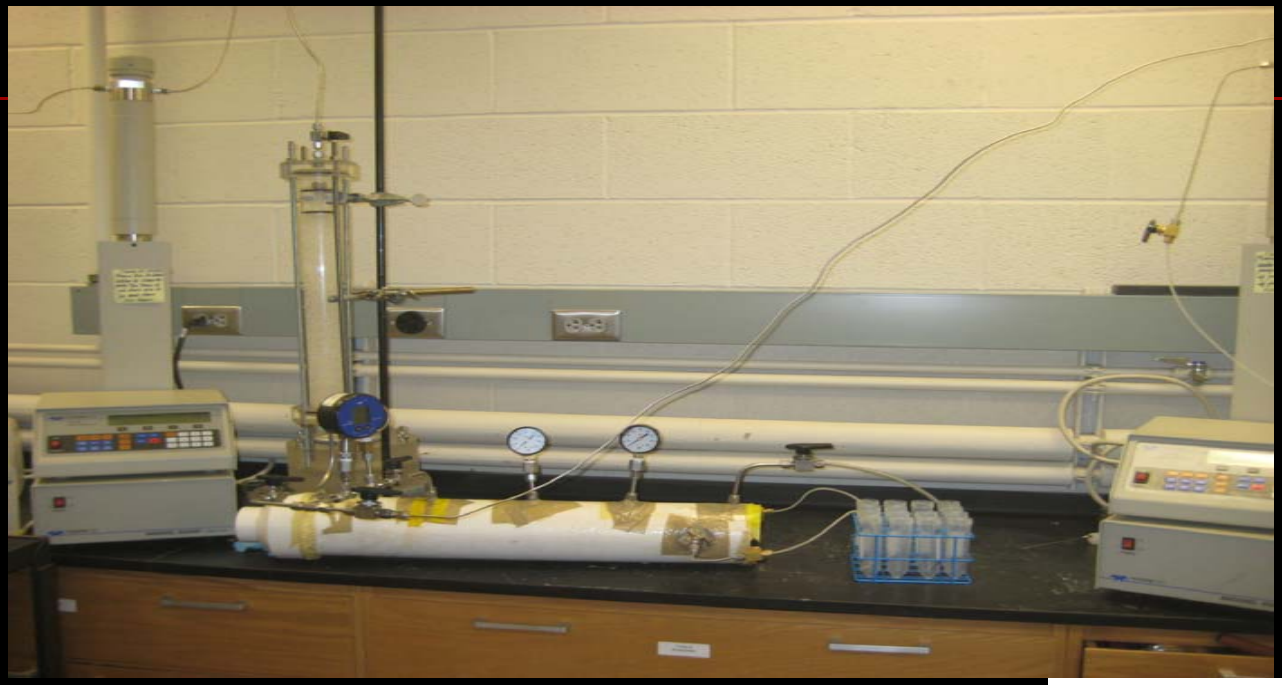
- Injecting Brine into Gel in the fracture

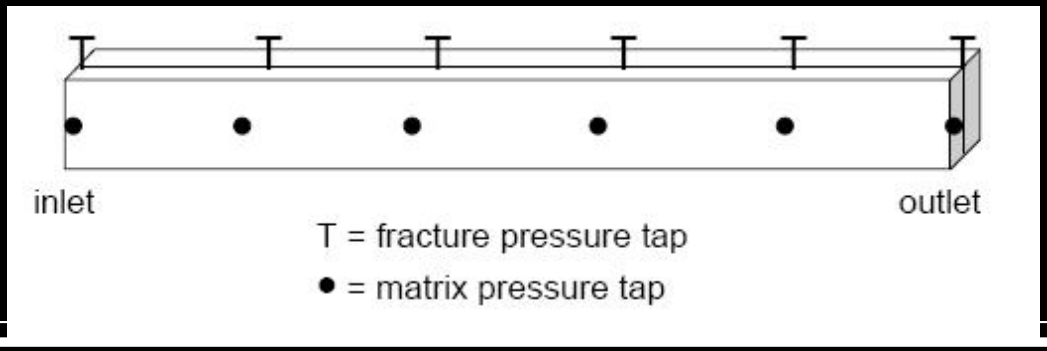
Does PPG Damage a Low Permeable Formation?

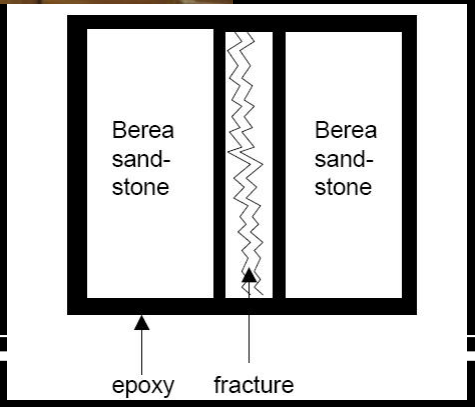
A Reservoir with Fracture(s) or Super-K Channels



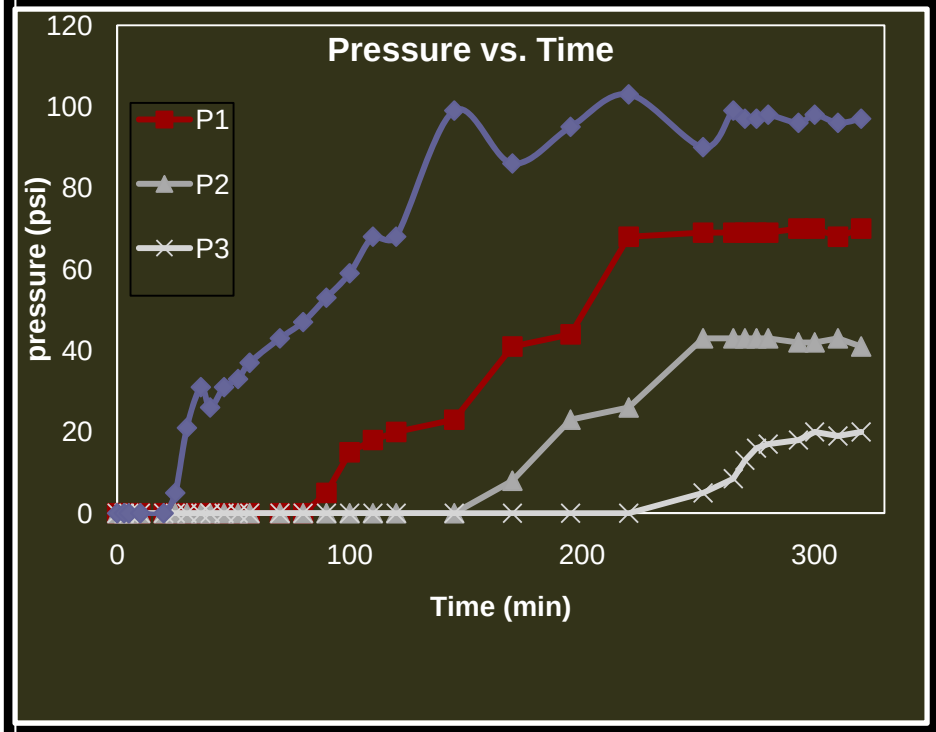
Open Fracture Model (SandStone)

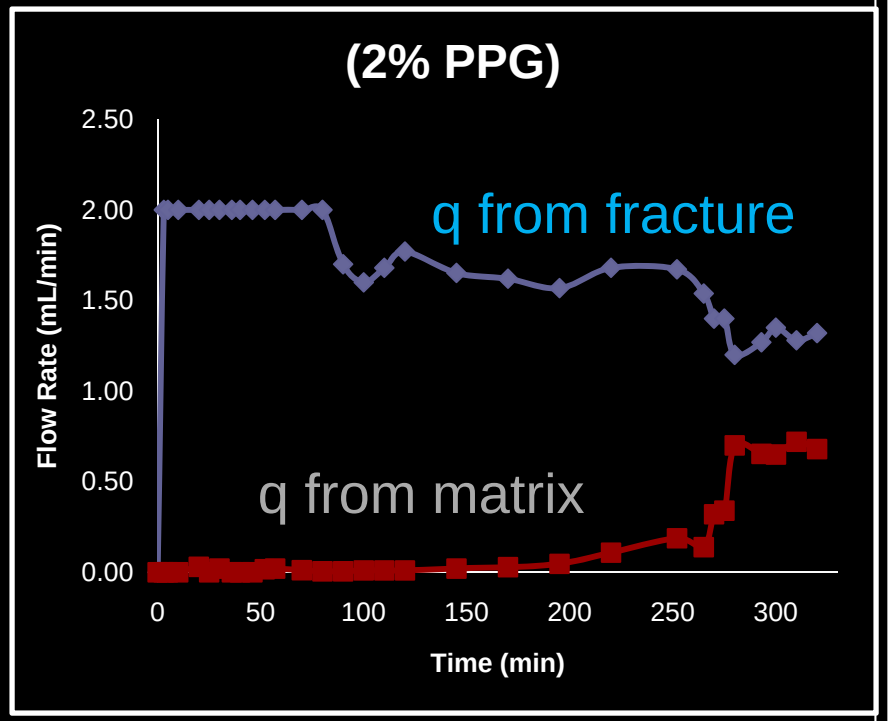




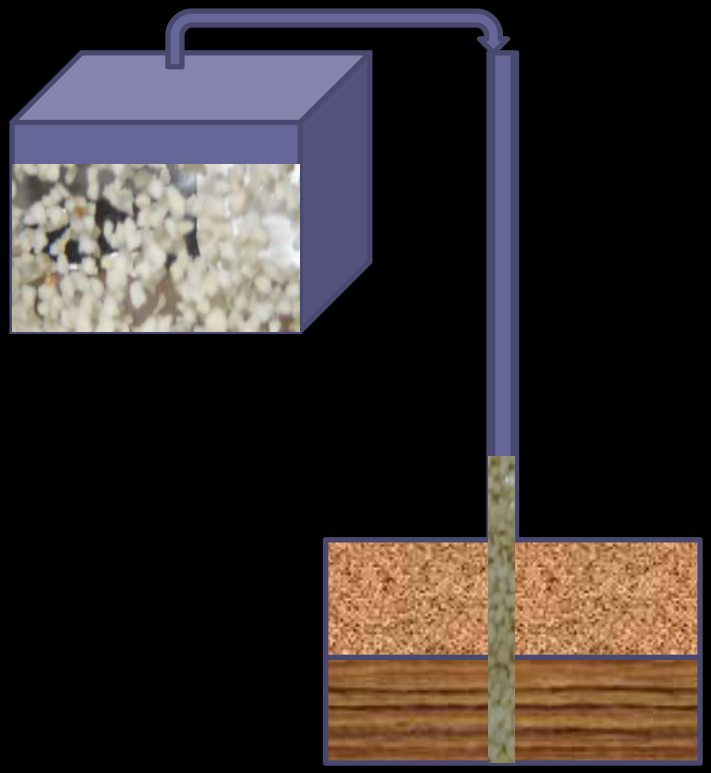


Fluid flow from matrix Indicates PPG does not damage low permeable matrix



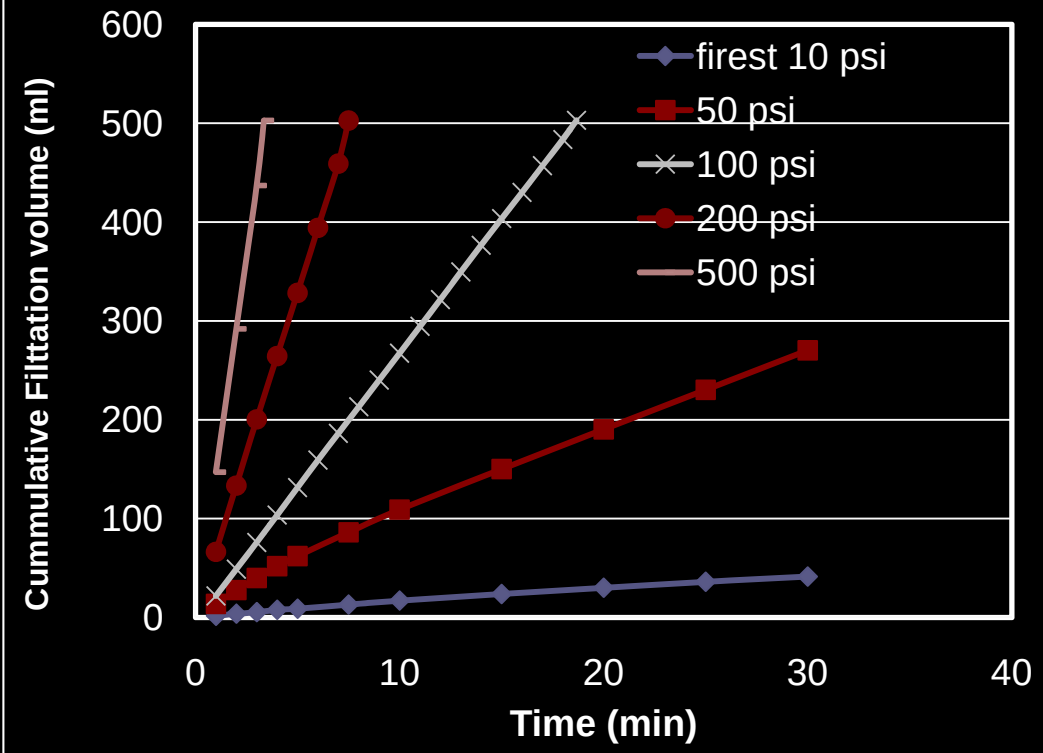


A Reservoir without fractures or Super-K Channels



Filtration Experiments have demonstrated PPG Does not Damage Low Permeability Zones/Areas

1. Filtration Results



2. Calculated Permeability of Gel pack

p=50 psi, k_{gel} = 656 md

p=100 psi, k_{gel} = 461 md

3. Comparison of Rock Permeability before and after PPG injection

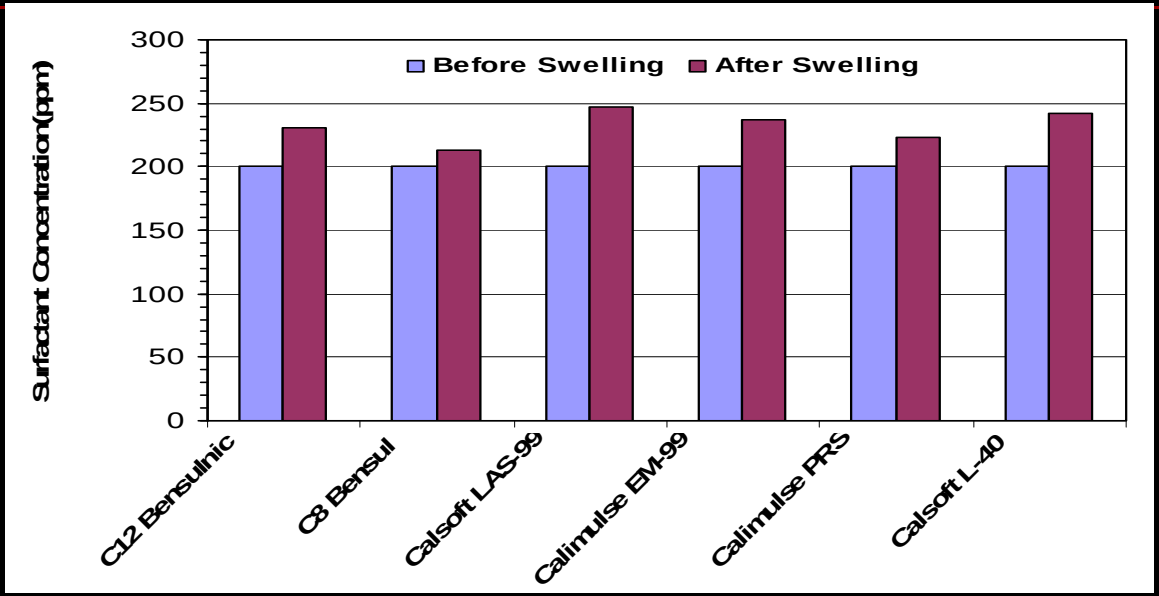
Experiment No.	K_b	K_a
Exp 1 (1%)	27	25.5
Exp 2 (0.05%)	27	25. 4
Exp 3 (10%)	56	49.6
Exp 4 (0.25%)	8	8

Task 6: Novel Methods

Objective : a few novel processes will be tested to determine if they can improve gel particle treatment efficiency.

Contribution: a novel EOR method was developed--- Forced Imbibition through the Combination of PPG and Surfactant

Concentration Change of Surfactants

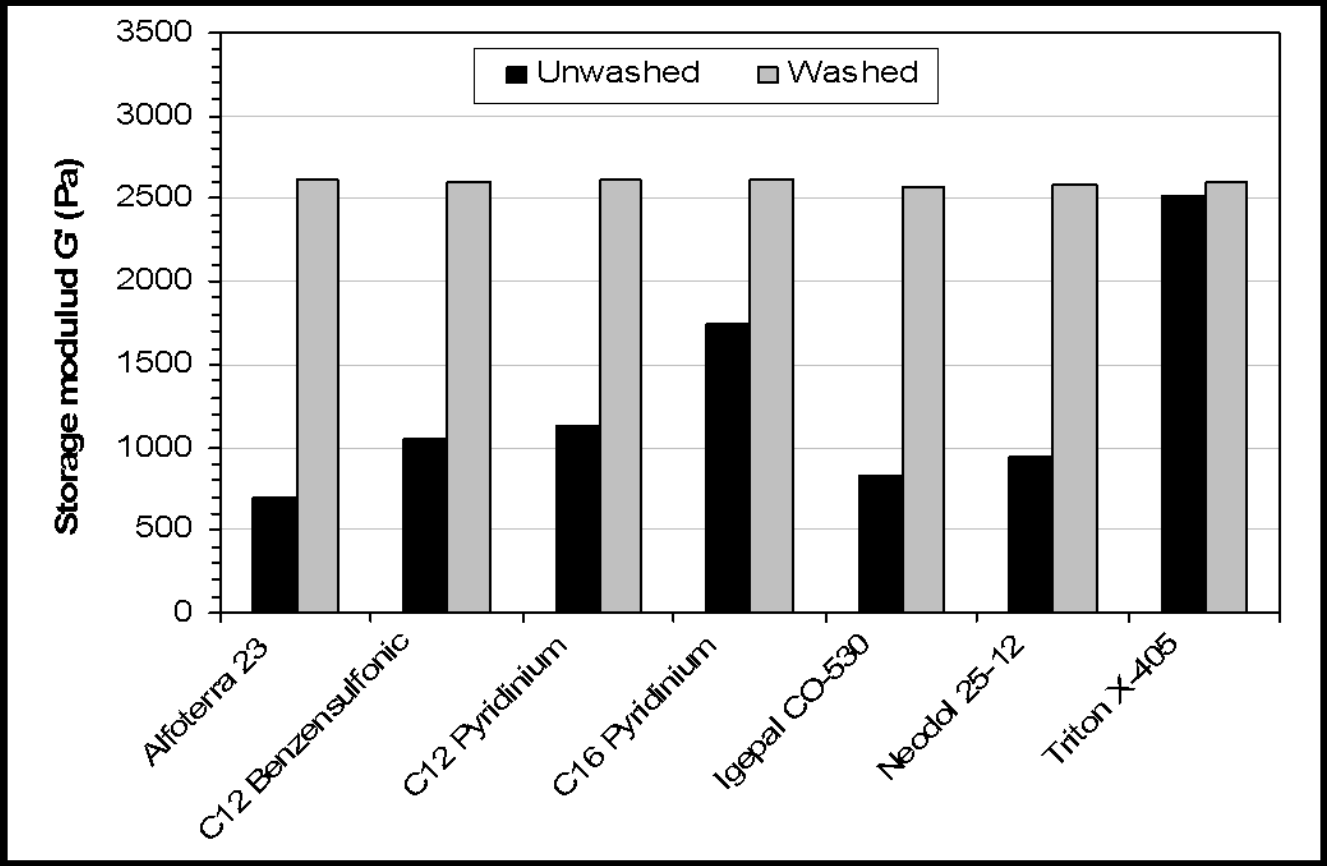


C12 Bensulnic	Sodium dodecyl benzensulfonic acid
C8 Bensul	Sodium 4-n-octyl benzene sulfonate
Calsoft LAS-99	C_{10}~C_{16} alkyl benzensulfonic acid, PILOT Inc.
Calimulse EM-99	C_{10}~C_{16} alkyl benzensulfonic acid, PILOT Inc.
Calimulse PRS	Dodecyl branched benzensulfonic acid, PILOT Inc.
Calsoft L-40	Sodium dodecyl benzene sulfonate, PILOT Inc.

Gel strength was significantly reduced after mixed with surfactant solutions

Surfactant	Conc. in 1.0% NaCl	G' (Pa)	Change
In 1.0 wt.% NaCl	brine	2582	0%
Alfoterra® 23	1.93×10^{-3} M	689	-73%
Sodium salt, dodecylbenzene sulfonic acid	2.87×10^{-3}M	1042	-60%
n-Dodecylpyridinium chloride	3.52×10^{-3} M	1133	-56%
(1-Hexadecyl)pyridinium bromide	2.45×10^{-3} M	1739	-33%
Igepal® CO-530 (HLB=10.8)	2.16×10^{-3} M	824	-68%
Neodol® 25-12 (HLB=14.4)	1.35×10^{-3}M	946	-63%
Triton® X-405 (HLB=17.6)	5.68×10^{-4} M	2517	-3%

After surfactant molecules were washed off, the gel strength recovered to the value of PPG swollen in 1% NaCl.



Task 7: Customized PPG Products

- Objective: To provide a series of customized, well-characterized laboratory scale PPG products that cover a wide range of size and chemical characteristics.

PPG Products

- Size Adjustable: 10 um- a few mm
- Swelling Ratio: 10~200 times original
- Salt Resistance: All salt types and concentrations are acceptable
- Temperature Resistance: High to 110 ºC
- Long-term Stability: more than 1 year below 110 ºC.

Conclusions

- PPG has been successfully synthesized in the laboratory and on a commercial scale.
- PPG strength and size can be controlled. It has high temperature and salinity resistance.
- PPG can overcome some distinct drawbacks inherent to in-situ gelation systems.
- PPG can be added to produced water for injection into target wells. This avoids use of fresh water and so has an environmental advantage.

Conclusions (cont.)

- There is no injectivity problem for large volume of mm-size PPG treatment for most wells in mature oilfields.
- Real-time PPG injection pressure response can be used to adjust PPG particle size concentration to better fit reservoir.
- Preliminary experiement results show PPG dose not damage unswept low permeable zones/areas.
- A new technology---Forced Imbibition through combination of surfactant and PPG treatment is developed.

Acknowledgement

- **Financial Support from RPSEA & Missouri S&T**
- **Researchers**

Missouri S&T

Postdoc fellow: Dr. Yongfu Wu

PhD students: **Mahmoud Elsharafi**, Jia Zhou, Zinan Li

Master student: Rajesh Challa, Hao Zhang

ChemEOR: Dr. Patrick Shuler

BJ Service: Dr. Qu Qi, Jennifer Cutler

Questions?

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Comparison of PPG with In-situ Gel

	PPG	Bulk Polymer Gel
Chemical reaction	Manufactured particle, no in-situ reactions	Affected by interactions with reservoir rocks and fluids
Temperature Resistance	110 ^{o}C	Depend on polymer, usually below 90 ^{o}C, especially for Low Concentration Gel
Salinity Resistance	Any salt and concentration brine	Depend on polymer, more sensitive to divalent cationic
Possible damage on formation	Large particle, selectively enter super-K zones/interval	Like polymer flooding during injection. Gel may form in low permeability zones

Comparison of PPG with In-situ Bulk Gel

		PPG	Bulk Polymer Gel
Preparation of fluids	Water	Any convenient water	Usually fresh water required
	mixing	Quickly, well disperse	Usually 30-60 minutes
Injection Scheme		Slug, Alternated injection of PPG/W	Consecutive, Alternated slugs of W/Chemicals not allowed
Pressure monitoring as an indicator during injection		Quick, good diagnostic to adjust particle size, strength and conc.	Not a diagnostic for gel behavior.
Costs		One composition	Polymer+Crosslinker+ Additives
Environmental		Friendly (Salty water)	Fresh water usually required

EOR Mechanisms of PPG Treatment

Oil Recovery

$$E_R = E_D \times E_A \times E_V$$

- E_R=Recovery Efficiency
- E_V=Vertical Sweep Efficiency
- E_A=Areal Sweep Efficiency

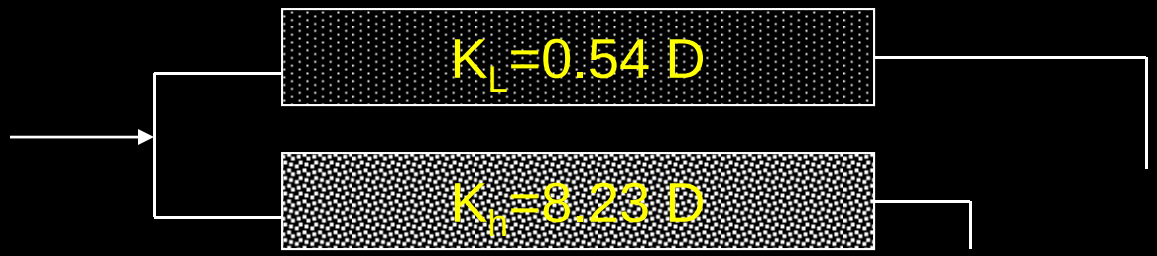
Biggest Impact – Selective Plugging

- E_D=Displacement Efficiency

Some Effect

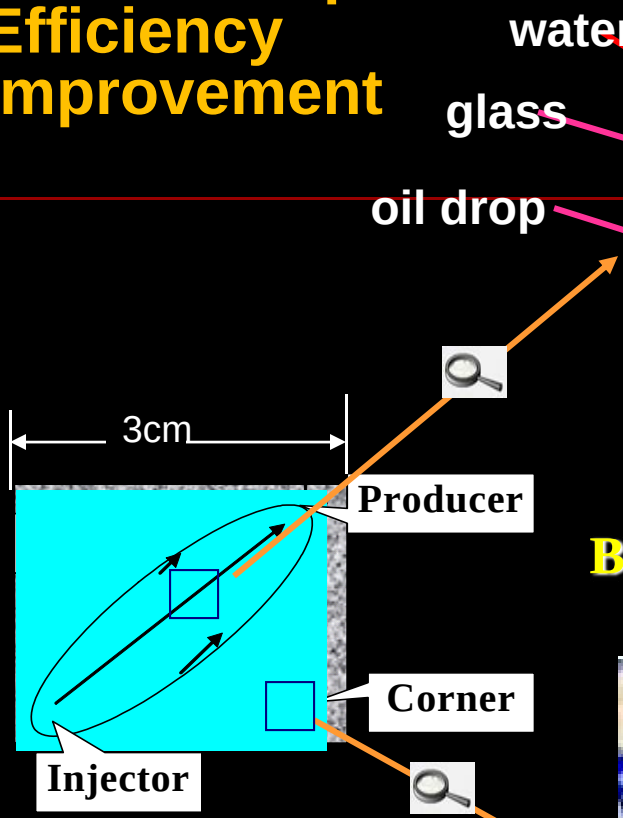
Experimental Results of Parallel Core Flooding
(Vertical Heterogeneity Model)

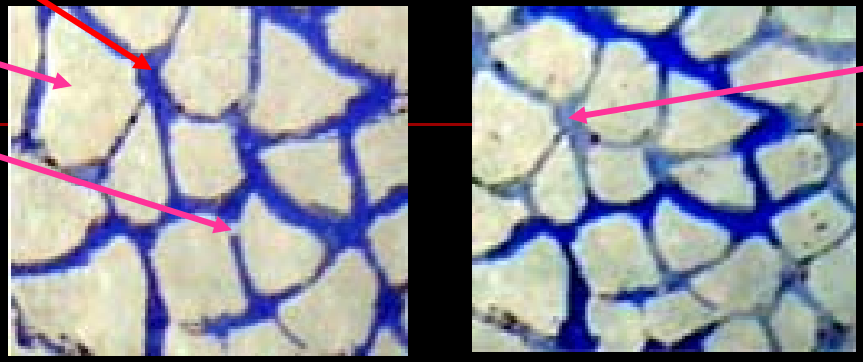
No.	Permeability (Darcy)	Split of Flow (percent)		Oil Recovery (98% water cut)		Total Oil Recovery	
		Before (%)	after (%)	before (%)	after (%))	Before (%)	After (%)
S1	8.23	91	20	70	75	46.8	64.9
	0.54	9	80	22	54		



Areal Sweep Efficiency Improvement

MICROMODEL DEMONSTRATION

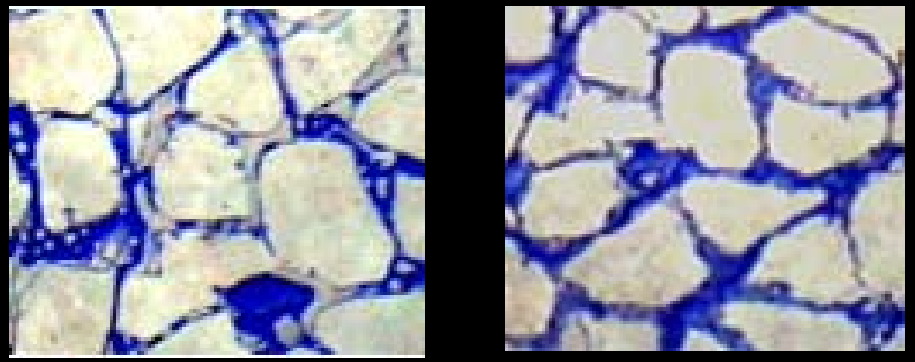




a. Remaining oil distribution in main stream

Before PPG Inj. → **After PPG Inj.**

More water diverted to corner after PPG injection

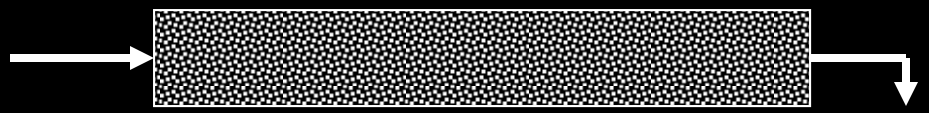


b. Oil distribution at corner – Now lower

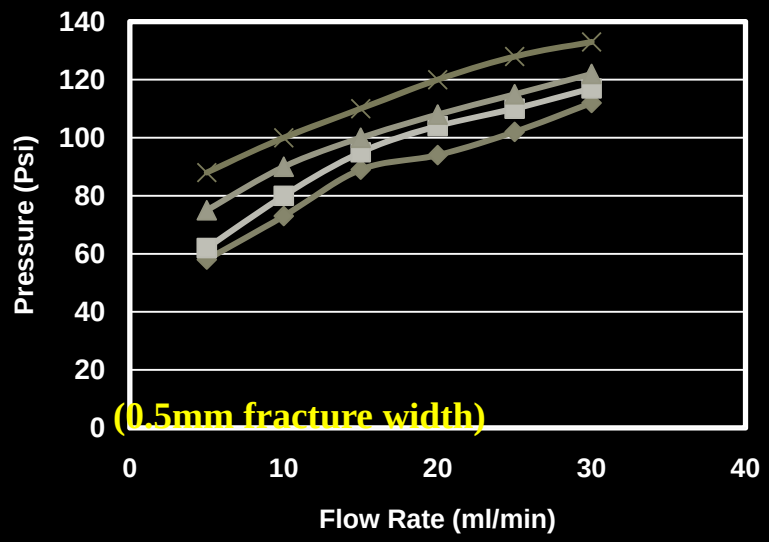
Experimental Results from Single Sandpack Demonstrates Improved Displacement Efficiency

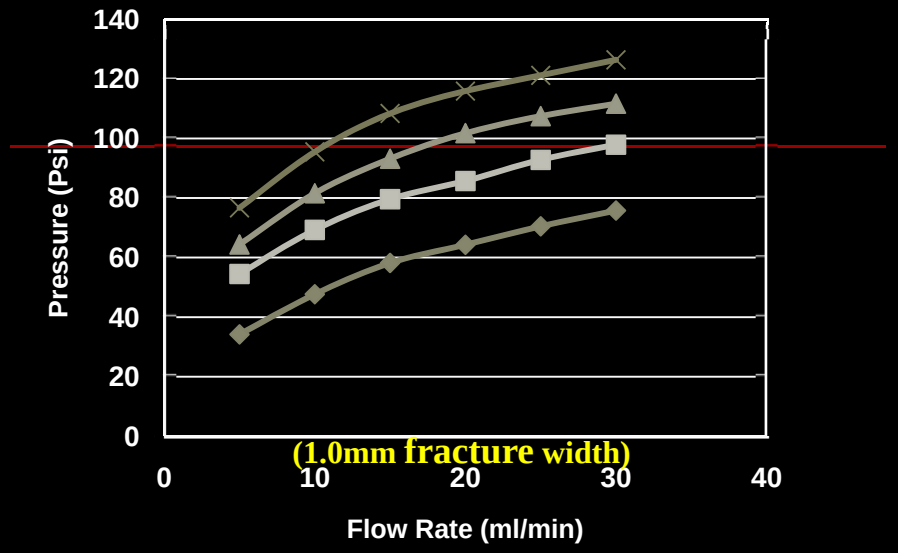
Core No.	K (D)	PPG Size *(mesh)*	Swi (%)	Oil Recovery[1] (%)	Oil Recovery[2] (%)	Increased Oil Recovery (%)
No1	22.5	*250*	22.4	62	73	11
No2	20.6	*160*	23.2	64	74	10

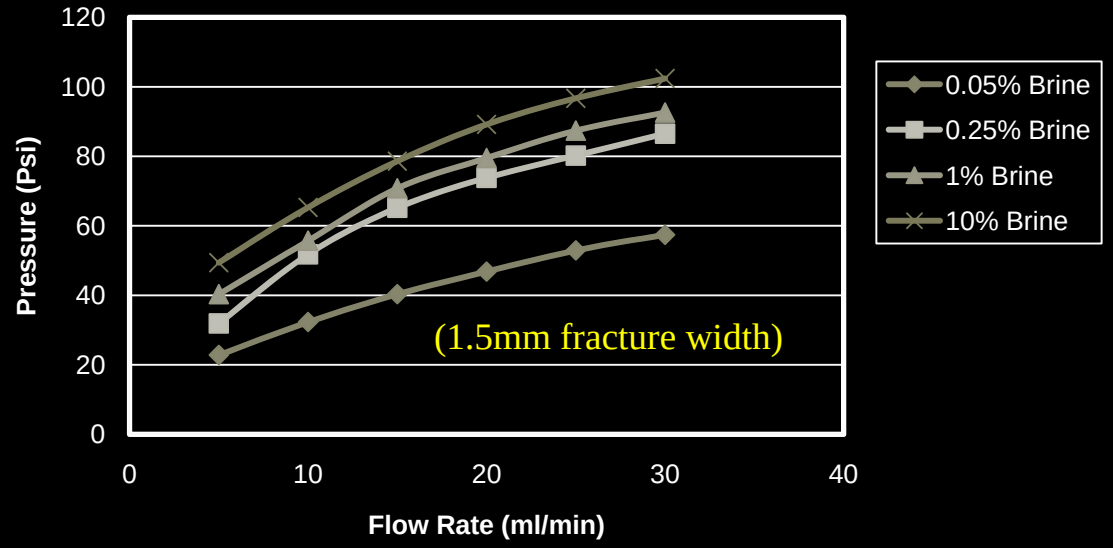
"1" refers to oil recovery from water flood before PPG injection
"2" refers to total oil recovery from both water flood and PPG treatments



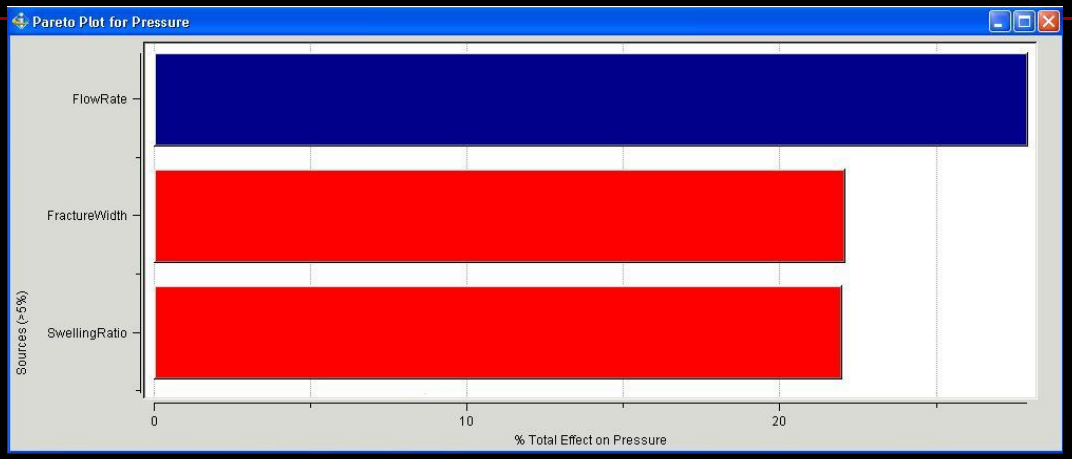
Fracture Pressure vs. Flow Rate & Brine Concentration

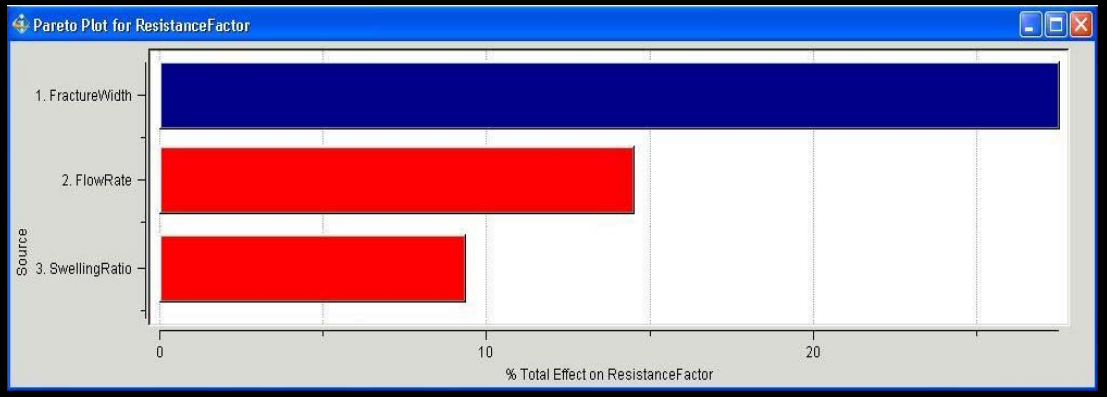




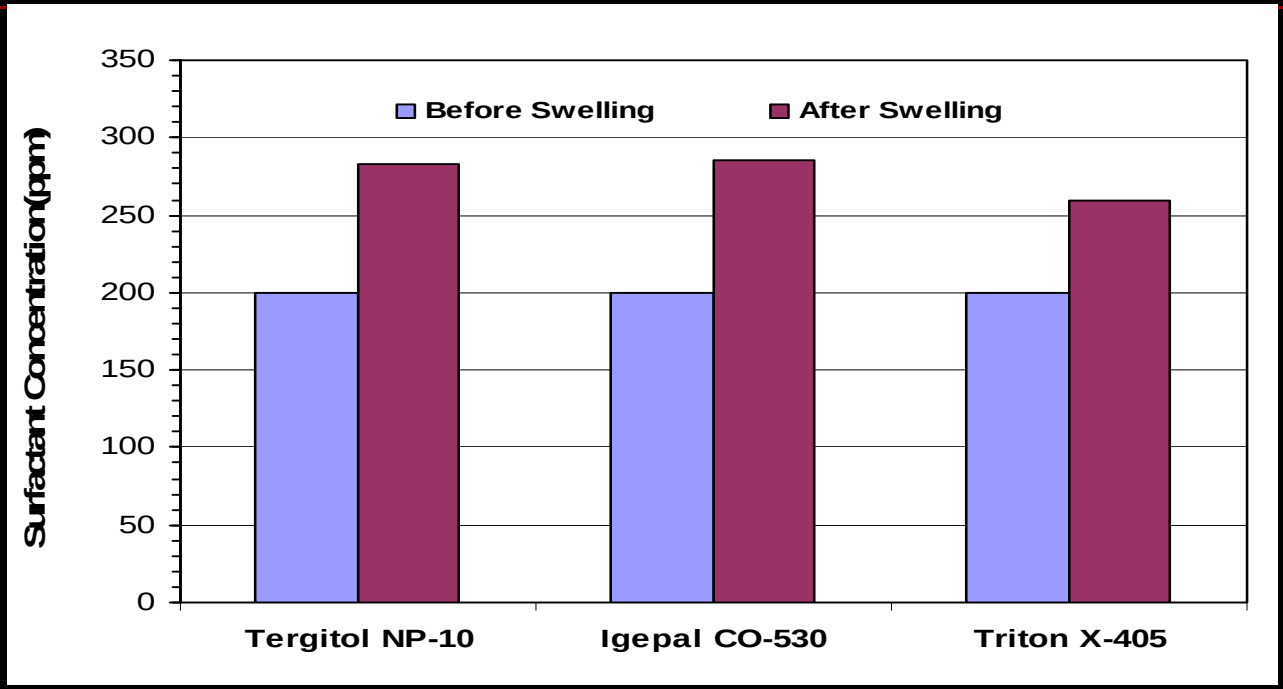


Ranking of Impact Factors





Concentration Change of Non-ionic Surfactants



Tergitol NP-10	Ethoxylated nonylphenol with 10 moles of EO, HLB=13.2
Igepal CO-530	Ethoxylated nonylphenol with 5 moles of EO, HLB=10.8
Triton X-405	Ethoxylated octylphenol with 40 moles of EO, HLB=17.6