How to maximize the value of mature HC fields?

Workshop

Budapest, 18. November 2010.

Society of Petroleum Engineers

TIORCO

A NALCO & STEPAN COMPANY

BrightWater ® Technology In-Depth Conformance

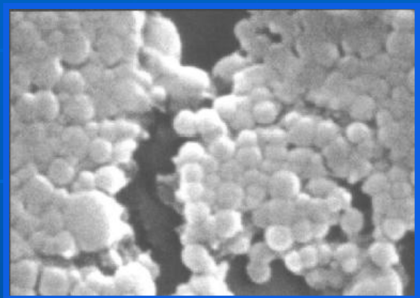
The BrightWater History

The BrightWater concept began in 1997 as a BP idea

It was considered high-risk / high-reward and was proposed as a Joint Venture project to the “MoBPTeCh” consortium.

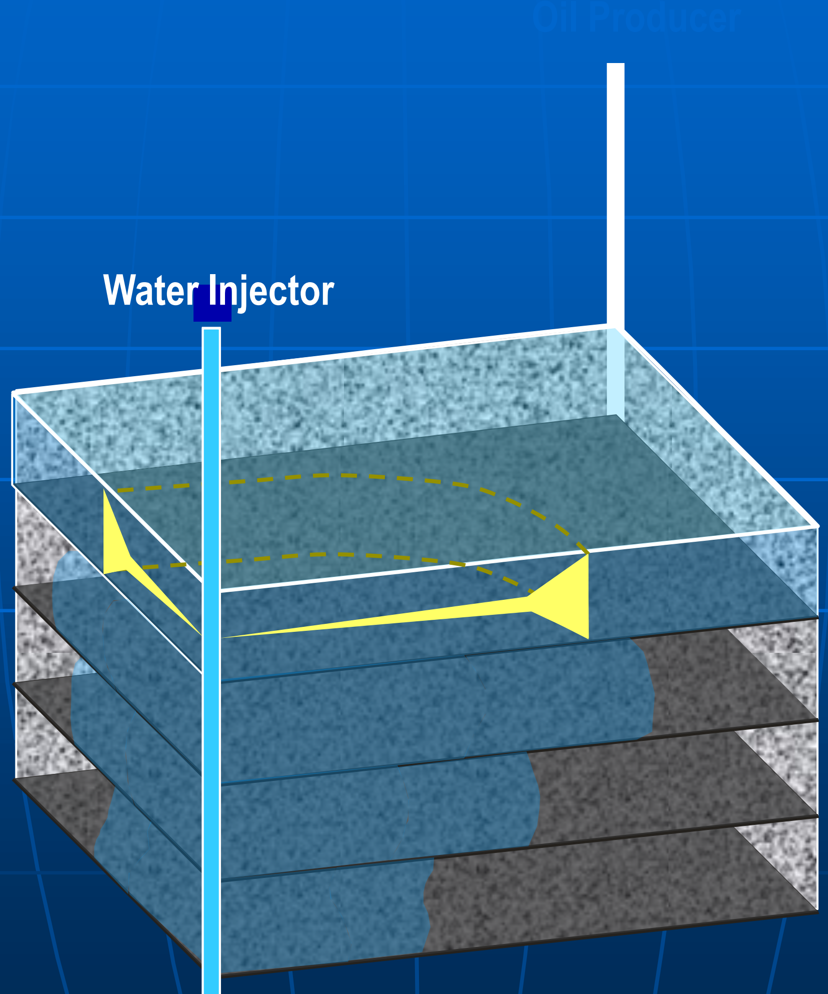
- 1997 - Subsequently adopted by **Mo**bil, **B**P, **Te**xaco, **Ch**evron as a viable project
- 1997 - Nalco was selected and agreed to join the project as an equal contributor
- 2001-2004 - MoBPTeCh becomes BP, Chevron and Nalco
- 2007 - Consortium completed the BrightWater project and disbanded

Changing the Water Sweep Pattern



BrightWater® at sub-micron form before injection

BrightWater® after application into the reservoir



Water is injected and sweeps only a portion of the oil in place

BrightWater® is injected which blocks the flow of water to previously swept areas and forces the water to sweep new oil from the injection well to the producer

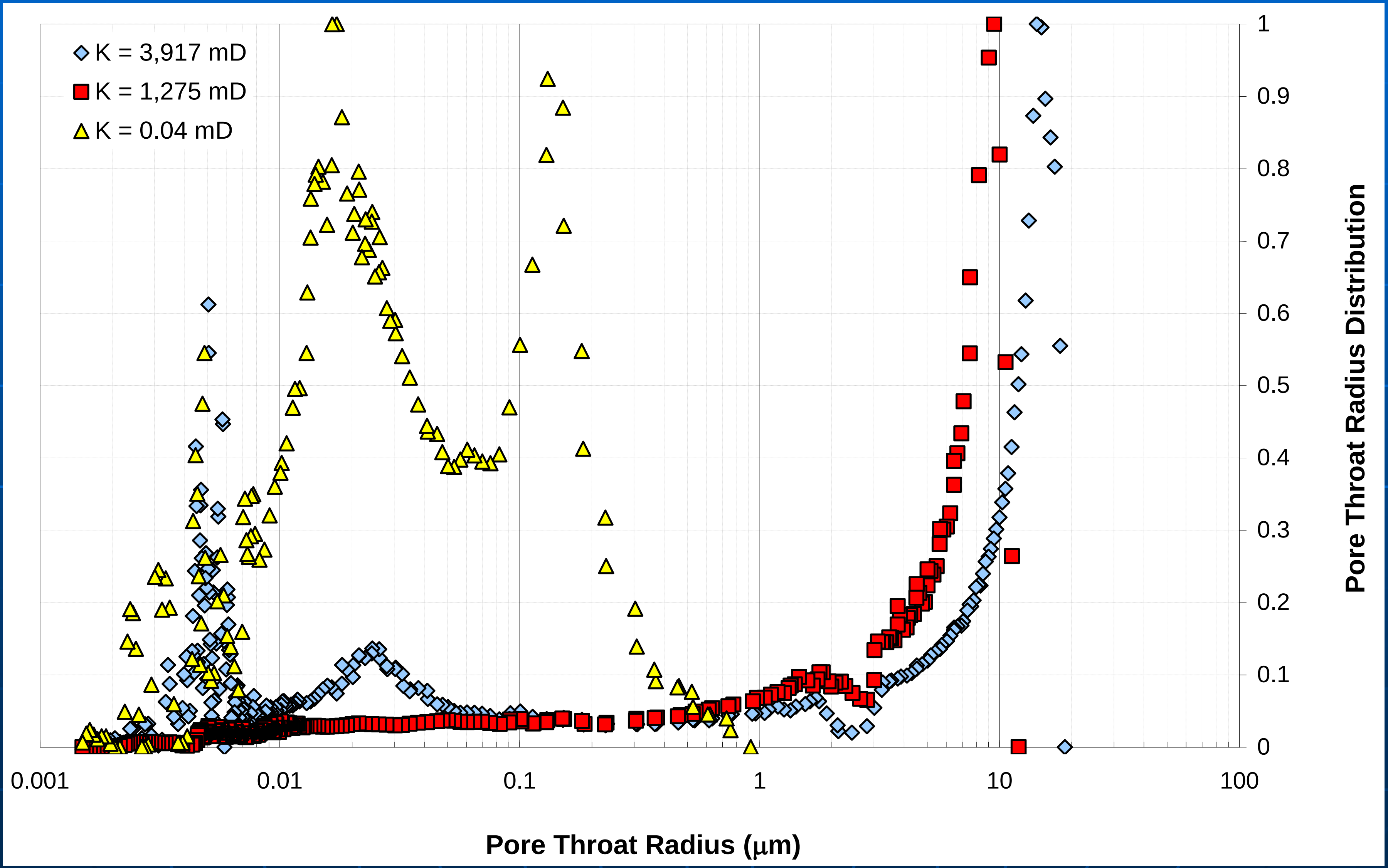
Particle Transition to Block

- The nano-particles are inert
  - Give virtually no viscosity or adsorption during injection
  - Much smaller than the pore throats they move through
- The expanded particles are "sticky", creating a high viscous (slow mobility) slug and/or block
  - They have increased solution viscosity, showing they now interact with each other
  - Propagated particles restrict water flow rate in the reservoir
  - Restriction can be permanent showing they are interacting with the porous rock

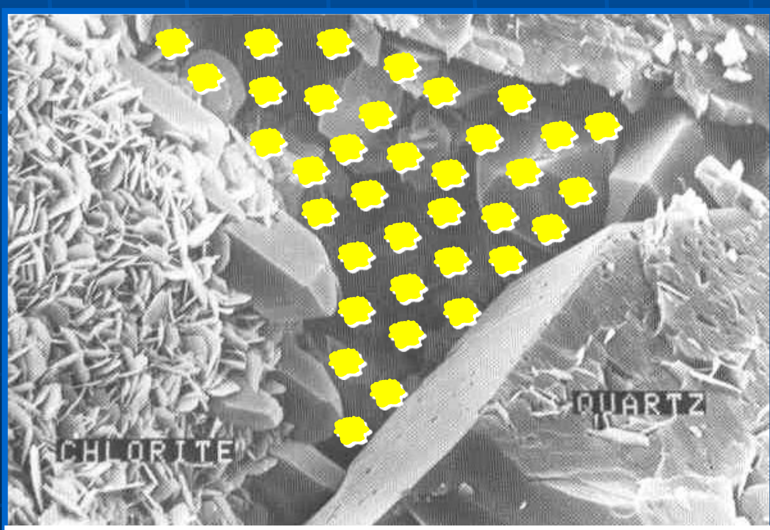
Nano-Particle:
Properties and Characteristics

- Manufactured particles average 0.1 micron in diameter
  Typical controlling pore throat size is much bigger than this for permeability of 500 mD or higher
- Density and viscosity of the BrightWater® technology as supplied (particles plus carrier fluid) is close to that of seawater
- During injection the dispersant strips off the carrier phase and ensures the particles are kept separated
- The Brownian Motion keeps the particles from settling prior to expansion in the targeted thief zone
- With the increase in temperature, the reversible crosslink breakdown and allow the particle to quickly expand, agglomerate and adhere to the rock formation, thereby increasing viscosity and creating a viscous slug/block

Pore Throat Radius and Distribution from Capillary Pressure



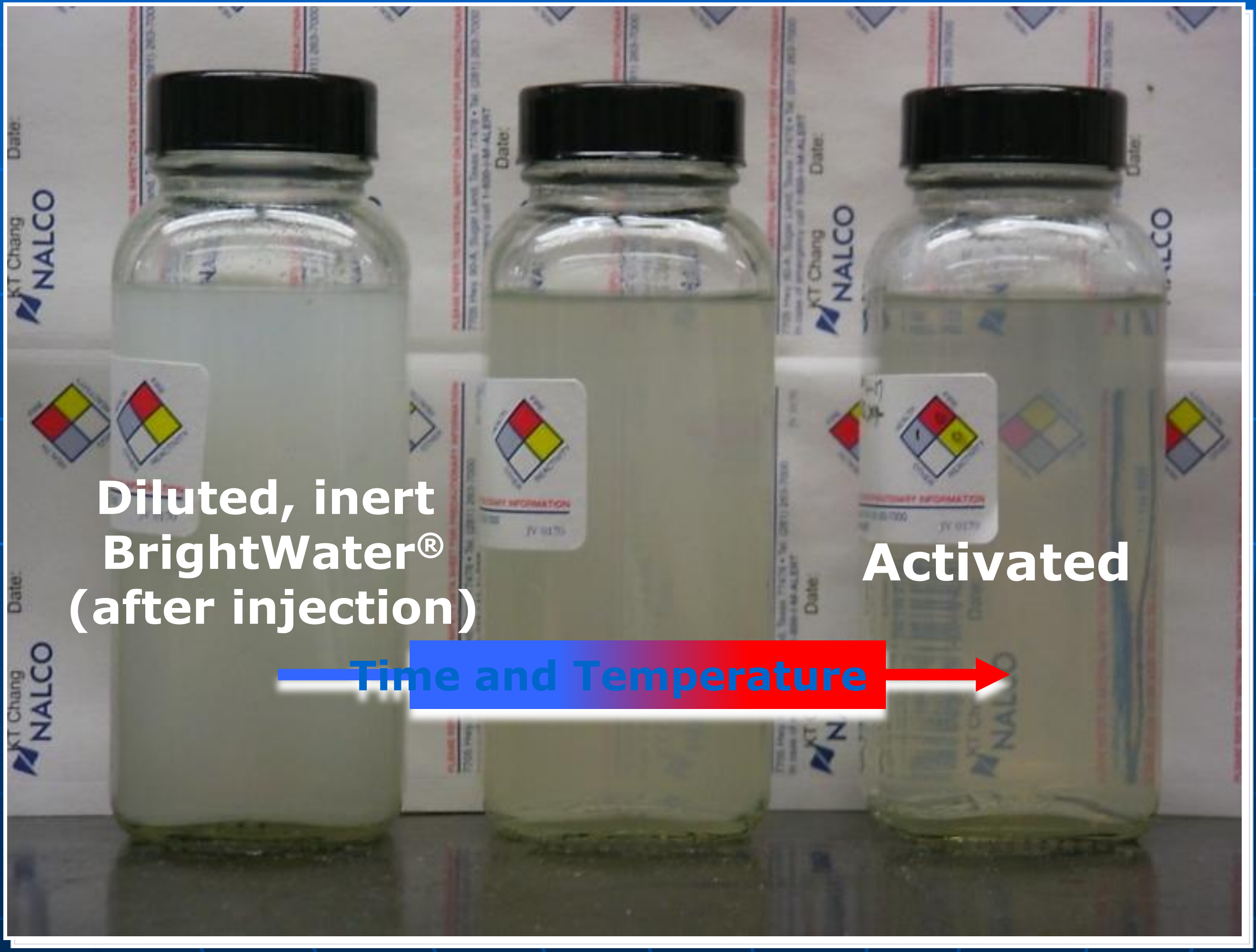
BrightWater Mechanism – Pore Scale

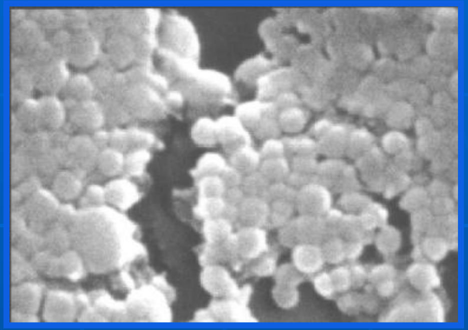


Representation of 5 micron particle in a pore throat

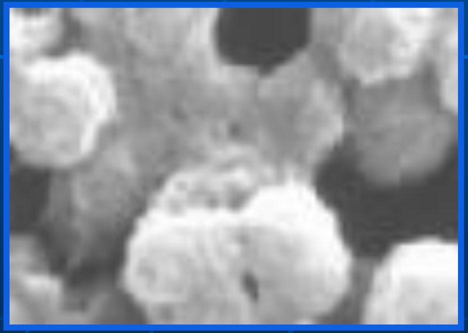
- The particle conformation expands as the crosslinks reverse
- Low levels of permanent crosslinker keep the particle from "decomposing"
- Particles aggregate

Reaction in the Reservoir





BrightWater® at sub-micron form before injection



BrightWater® after application into the reservoir

BrightWater - What's Different

- BrightWater material is NOT a classic viscous polymer or bulk gel
- Injects like water and is not damaged by shear during injection
- Deployed with conventional chemical injection equipment and existing injection system
- Enables EOR offshore applications
- No anticipated risk to reservoir or environment
- Well shutdowns are not required
- Restricts flow after popping
- One treatment may last from several months to years

BrightWater Grades (pH > 6)

- **Product Grades**
  - EC9368AHigh Temp. (180-250°F) (80-120°C)
  - EC9378AMed. to High (150-200°F) (70-90°C)
  - EC9398ALow to Med. (120-160°F) (50-70°C)
  - EC9404ALow Temp. (90-150°F) (30-65°C)
  - EC9408AVery Low Temp. (70-90°F) (20-30°C)
- **Dispersing Surfactant**
  - EC9360A For Fresh and Sea Water
  - EC9641A For Heavy Brine (70K-150K ppm)
  - EC9660A Winterized (Freeze-Thaw recoverable)

BrightWater - How to Design?

Design Steps

- Candidate selection / rejection criteria
- Lab evaluation and tests
- BW application design
- Simulation and economic evaluation
- Field operation design
- Post-treatment monitoring and evaluation

Candidate Selection Criteria

- Available movable oil at least 10% OOIP
- Early water breakthrough to high water-cut
- A high permeability contrast is desirable
- Reservoir temperature between 15° and 120°C
- Sandstone reservoirs
- Injection water pH > 6
- Expected tracer transit time >30 days
- Injection water salinity under 150,000 ppm
- Minimal natural fracture

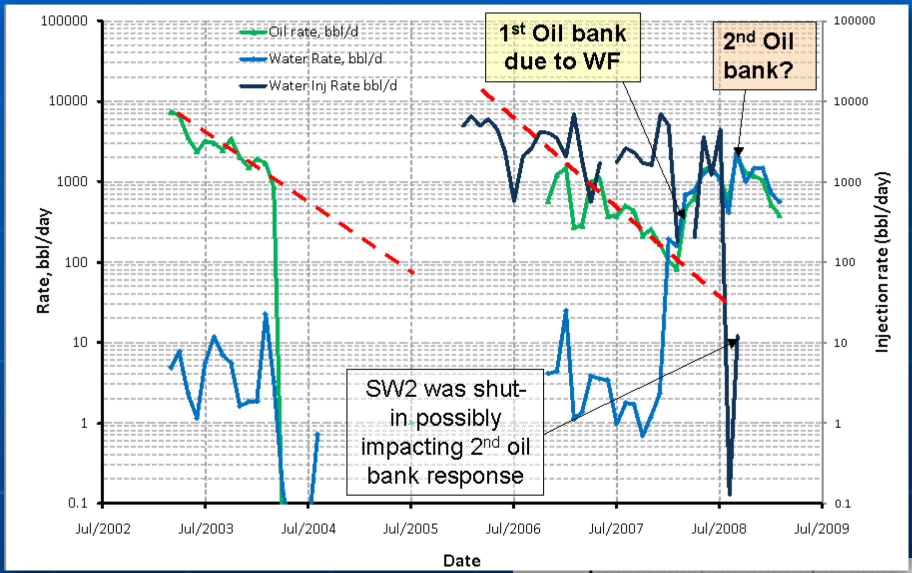
Candidate Rejection Criteria

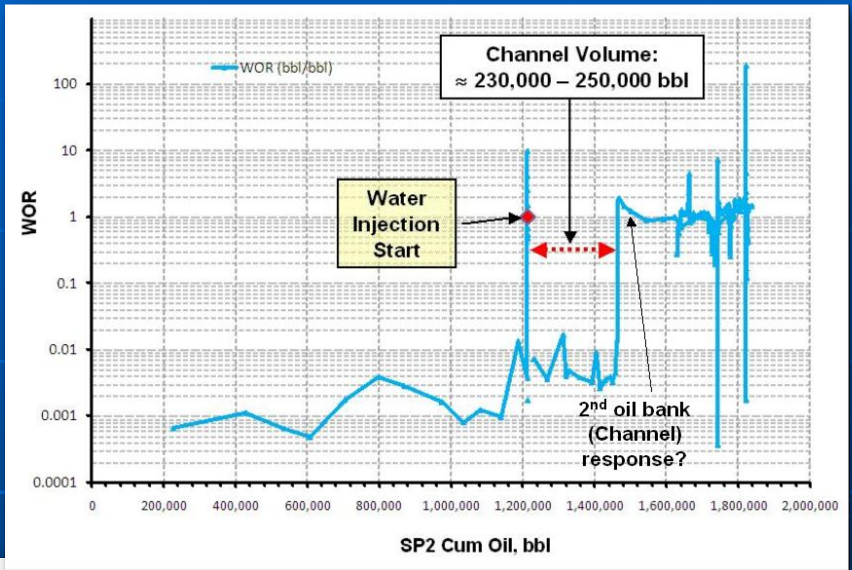
- Uniform formation or remaining mobile oil is <10%
- Injector is completed in an aquifer
- Very low permeability thief
- Fractured reservoirs, not carbonates (yet)
- Very slow water transit time (years)
- Highly acidic systems (pH < 6)
- Very viscous oil

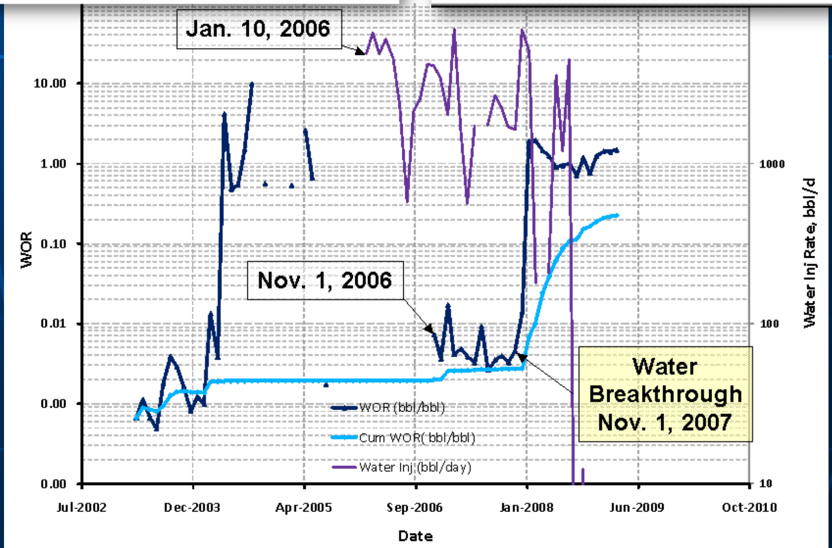
Treatment Design

- Determine the time between injection and activation. The ideal case is to activate / place the BrightWater halfway between the injector and producer (Injection/Production and/or tracer data)
- Determine the temperature (profile) that BrightWater will see in the target area (temperature logs & simulation)
- Use best matched grade of BrightWater
- Run bottle tests/ slim tubes/ core floods in lab at reservoir condition (Brine, pH, Temperature, etc.) to confirm viscosity / Resistance and Residual Resistance Factors

Estimating Channel Volume and Water Breakthrough from Injection/Production Data

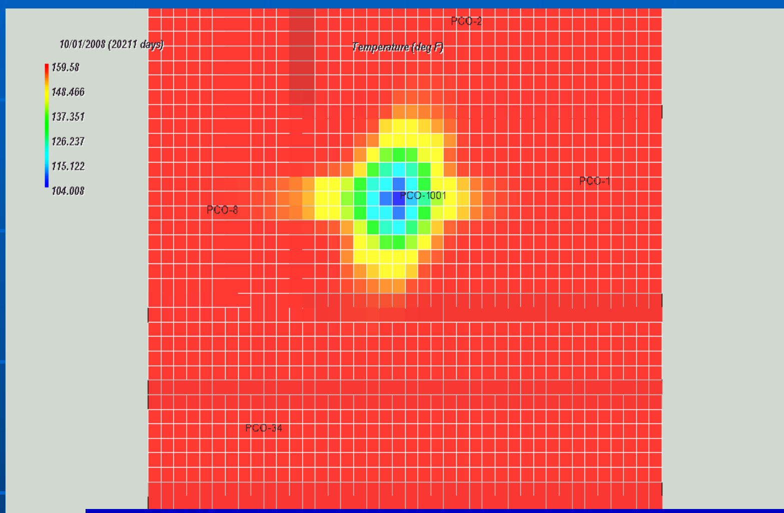


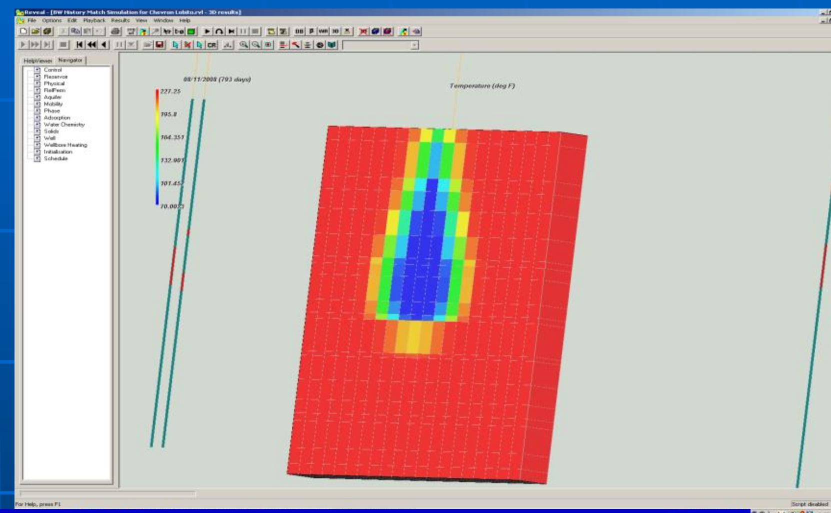


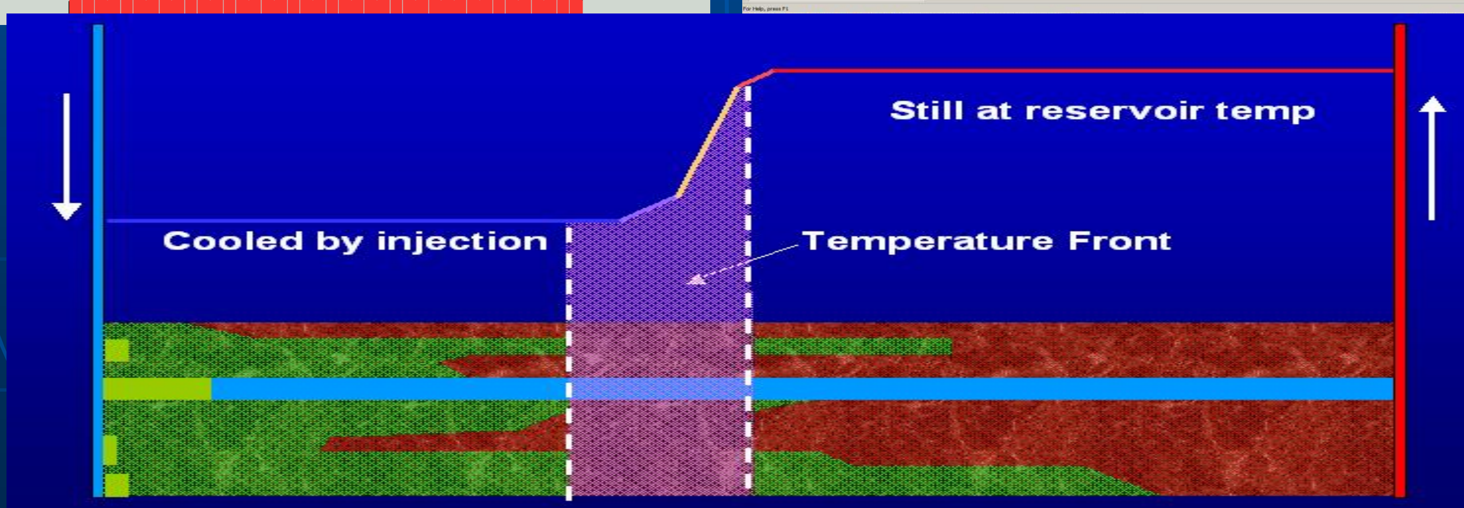


Temperature Front (Profile)

- Temperature front simulation to support BrightWater grade selection

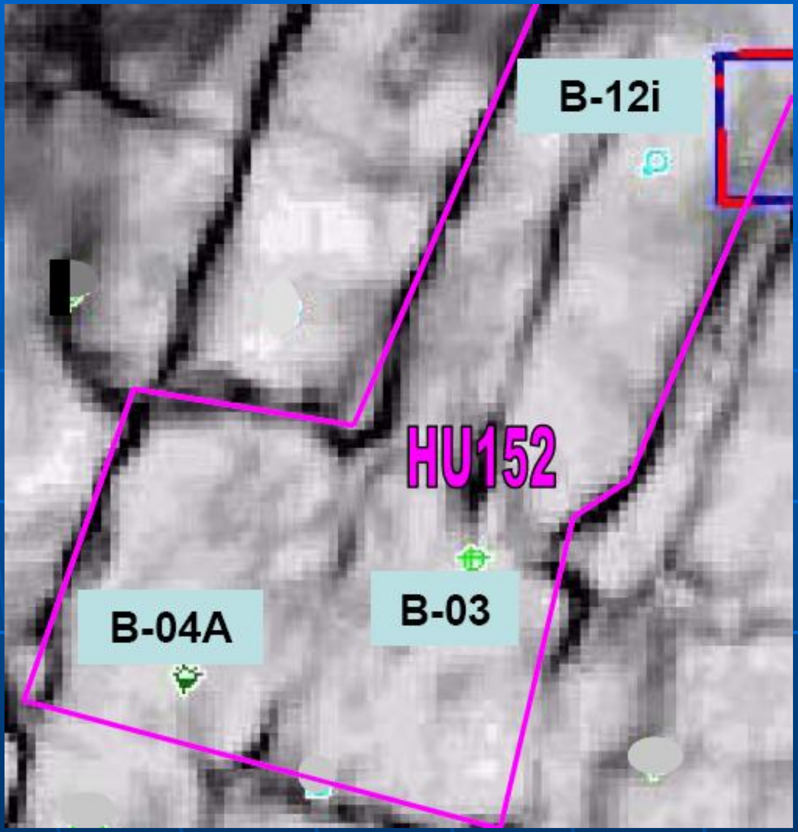


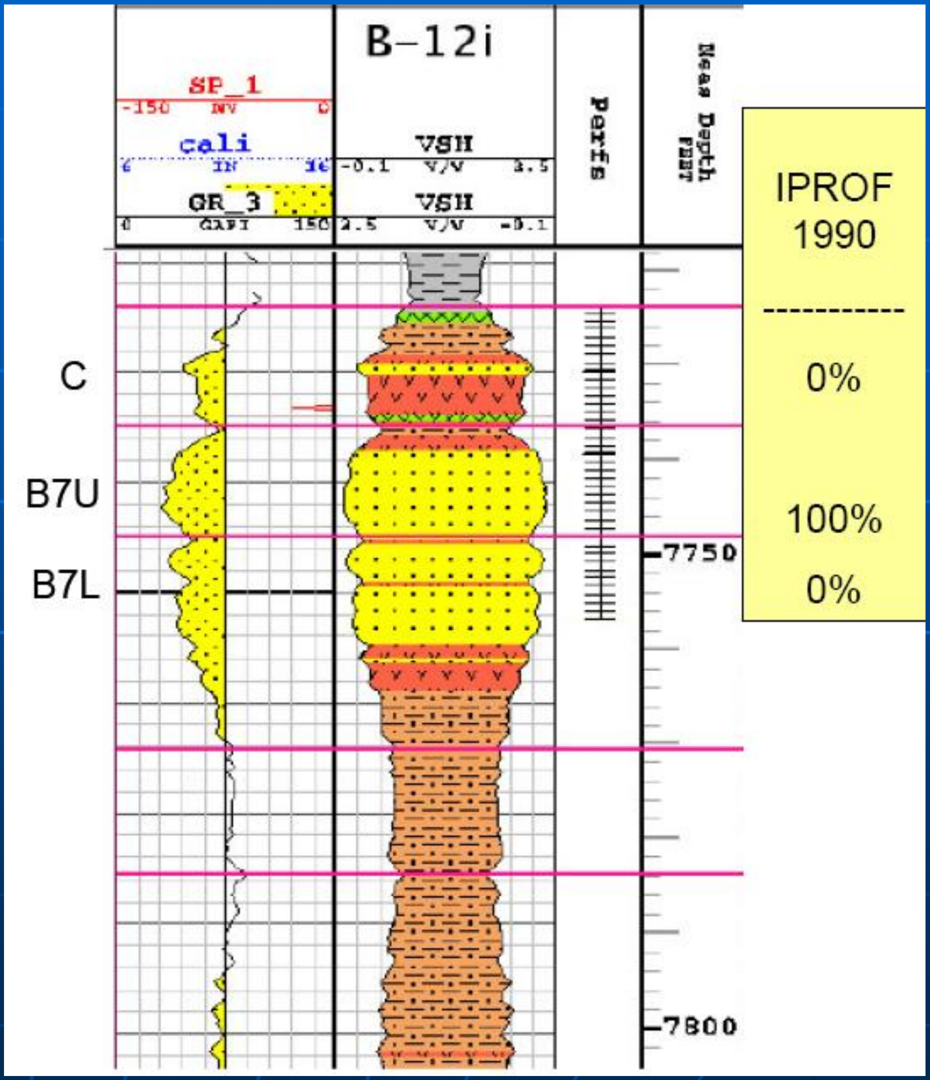




Case History – BP's Milne Point North Slope, Alaska SPE 121761

The Situation



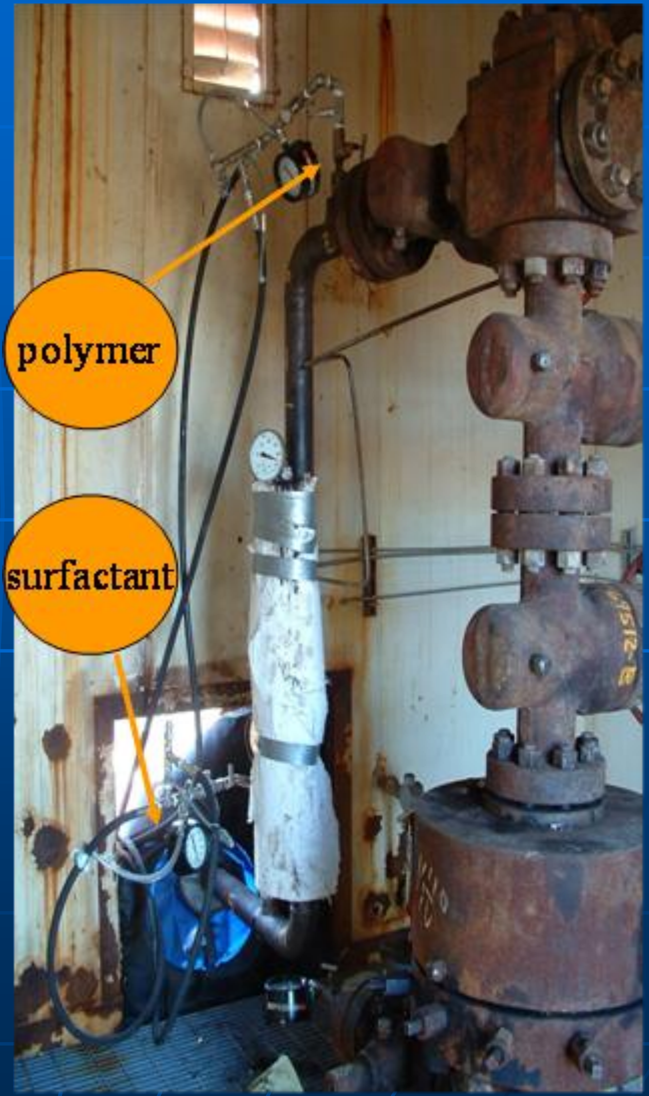


A well isolated hydraulic unit and a clearly defined thief zone

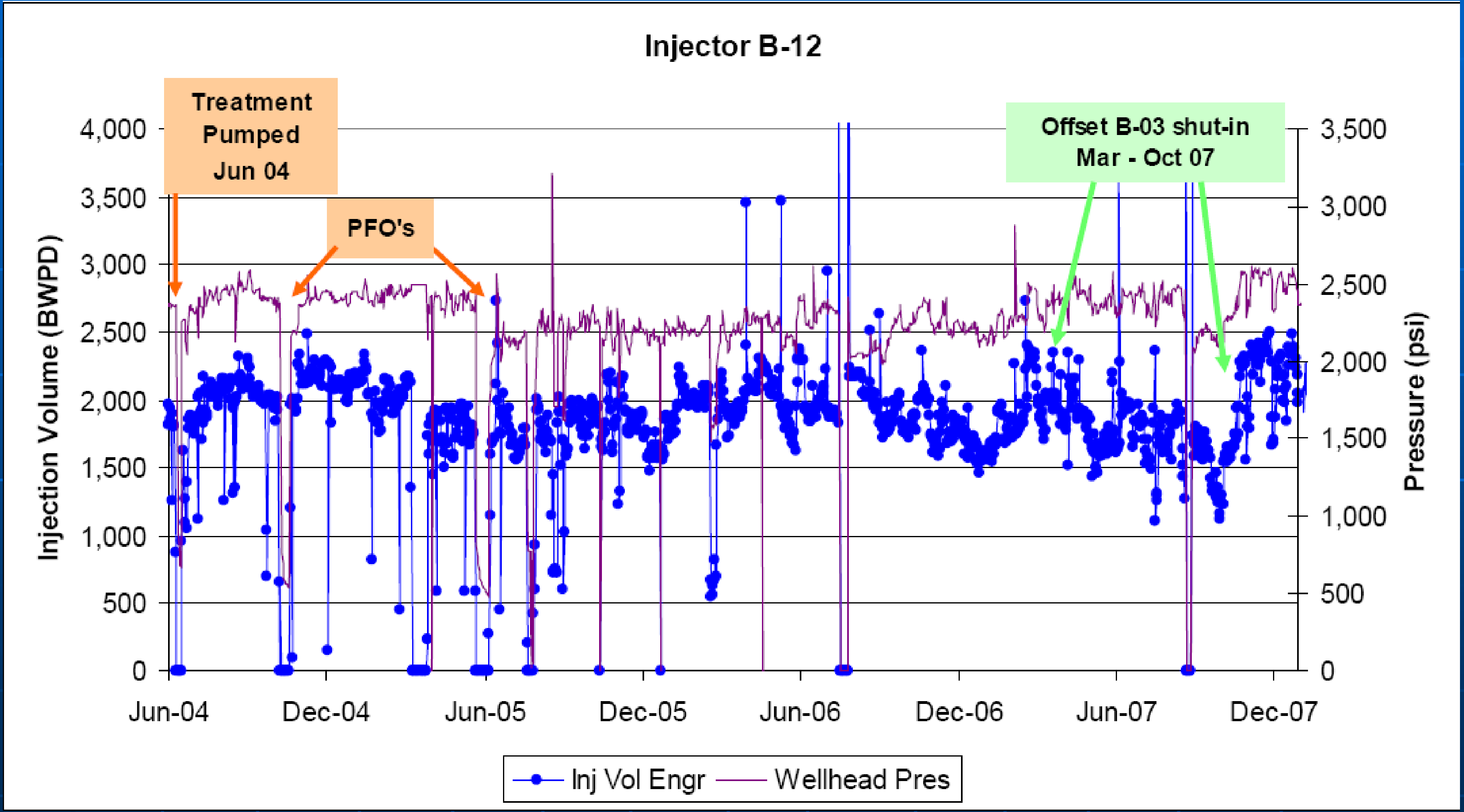
The Situation (Cont.)

- Recovery Factor only 20% at a water cut of 90%
- Formation temperature is 80°C (175°F) and the injection water is 43°C (110°F) at the perforations
- Assumed that water cycling is cause of low recovery
- Simulated and Chemical Tracers confirmed a breakthrough time of 12-18 months
- Inject 60 m3 of BrightWater Particle with 30 m3 of dispersing surfactant over 21 days

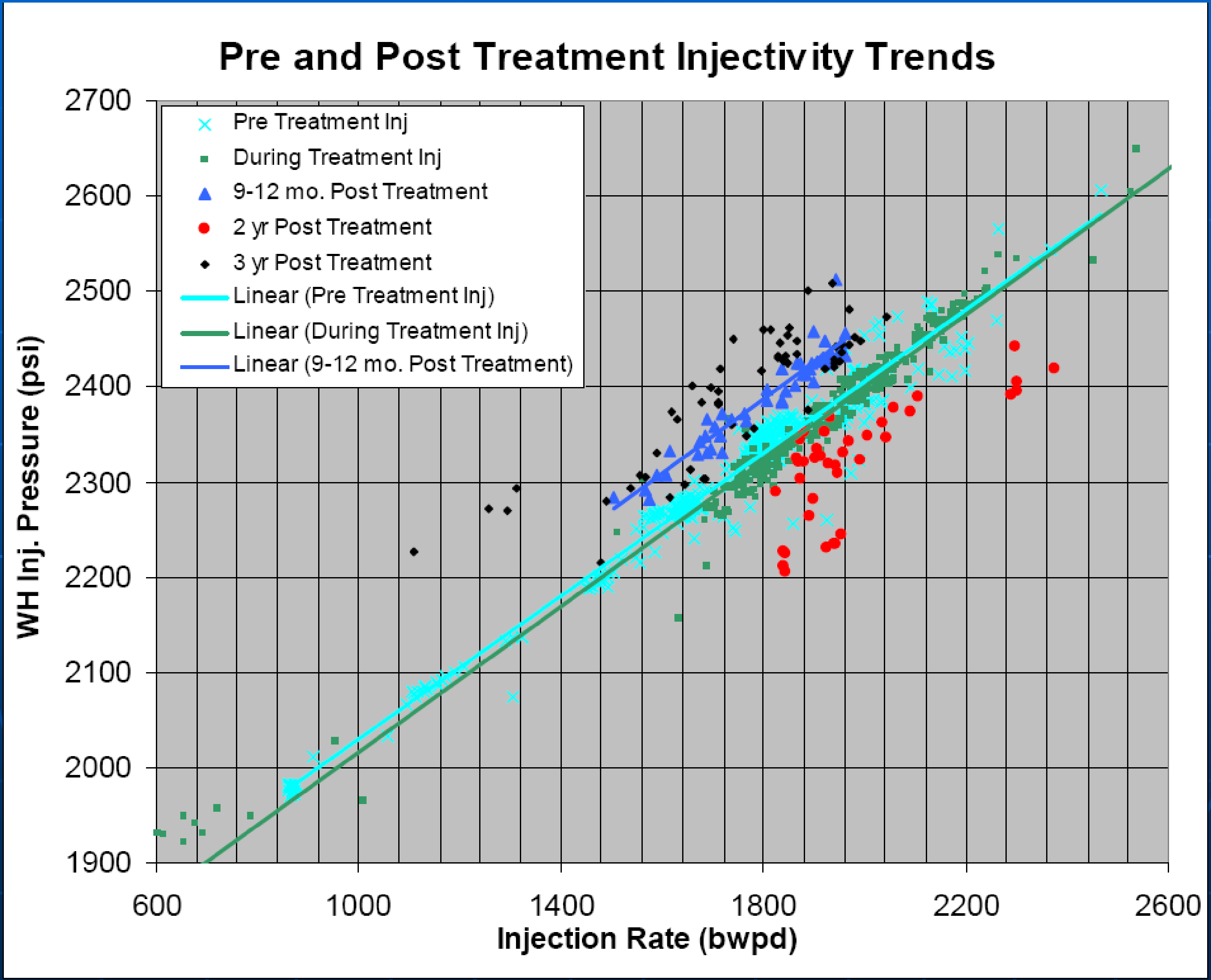
Pumping the Particulate System



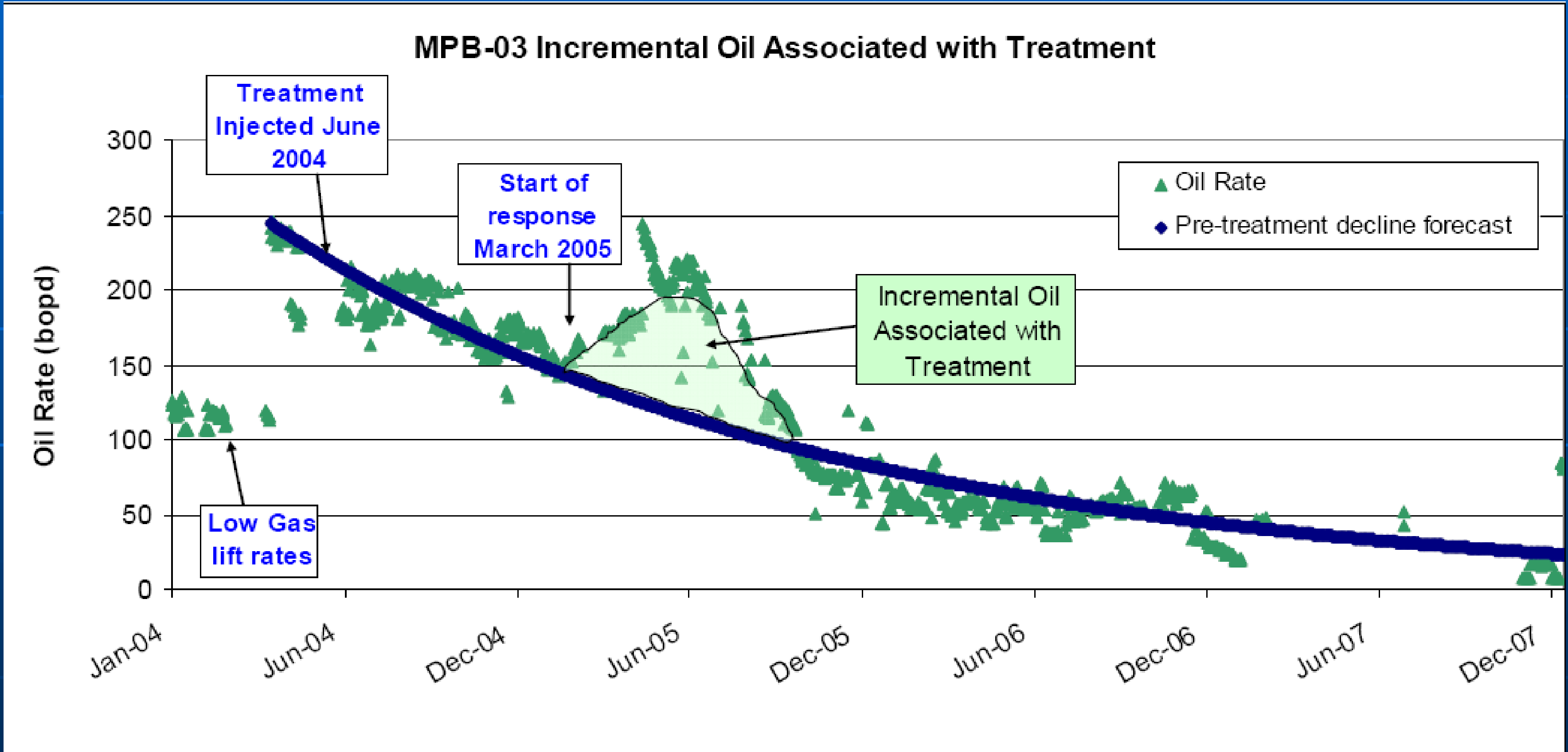
Injection Rates



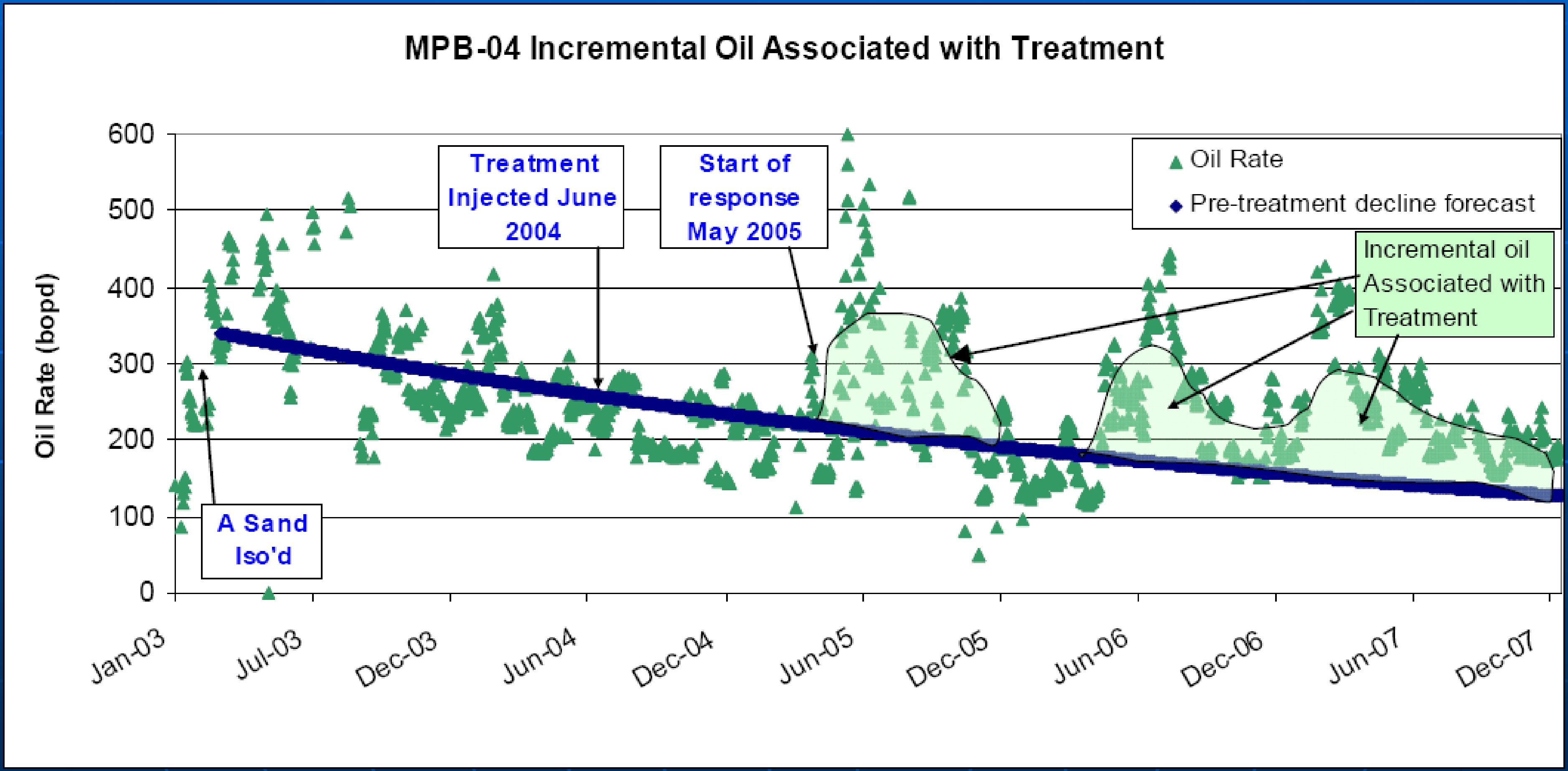
Injectivity Reduction



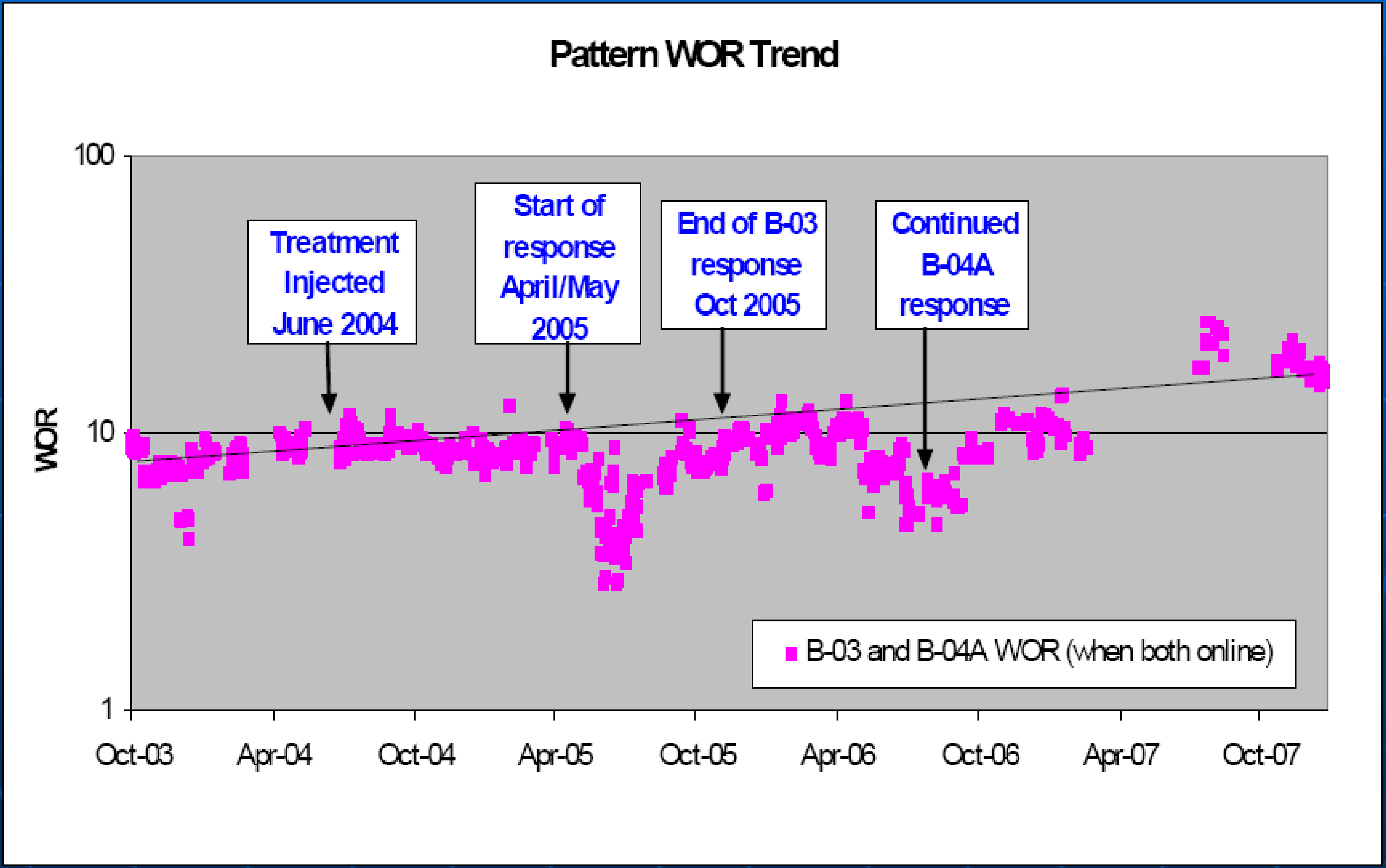
Production Response



Production Response Cont.



WOR Trend After BrightWater



Conclusions

- BrightWater treatments started late 2004 and Incremental oil production was seen by mid-2005
- Economics suggest incremental oil production under 5 $/bbl
- 2 other treatments performed in 2007 with more planned
- Agreement between field results and lab and simulation work was reasonably good

Publications on BrightWater

- Journal of Petroleum Technology
  - "Improving Sweep Efficiency at the Mature Koluel Kaike and Piedra Clavada Waterflooding Projects, Argentina", Jan. 2008
- Oil & Gas Journal
  - "Operators develop, implement new down hole technologies", Jan. 2008
- Petroleum News
  - "BP exploring in known ANS fields", Nov. 2007
- Frontiers, BP Publication
  - "Pop Goes the Polymer", Dec. 2007
- The BP Magazine
  - "The Bright Side of Technology", Issue 4, 2007
- 15th European Symposium on IOR, Paris, April 2009
  - Bright Water™ Sweep Improvement From The Lab To The Field
- SPE Papers:
  - 84897, 89391, 107923, 121761, 129732 ,129967, 131299, &136140

TIORCO
A NALCO & STEPAN COMPANY

Contact Information

Main Office Line – (303) 923-6440
2452 S. Trenton Way, Suite M
Denver, CO USA 80231

Pat Neal, Global Sales Manager
pmneal@tiorco.com

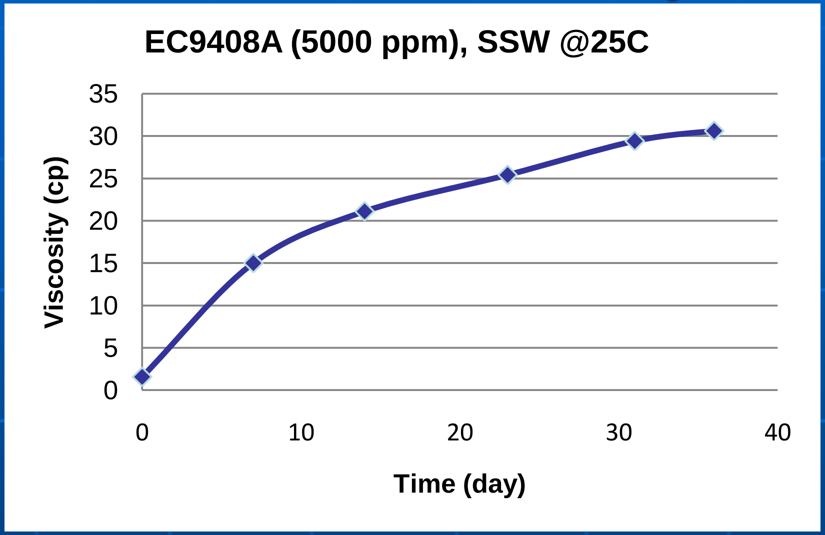
Thomas Altmann, Regional Manager
taltmann@nalco.com

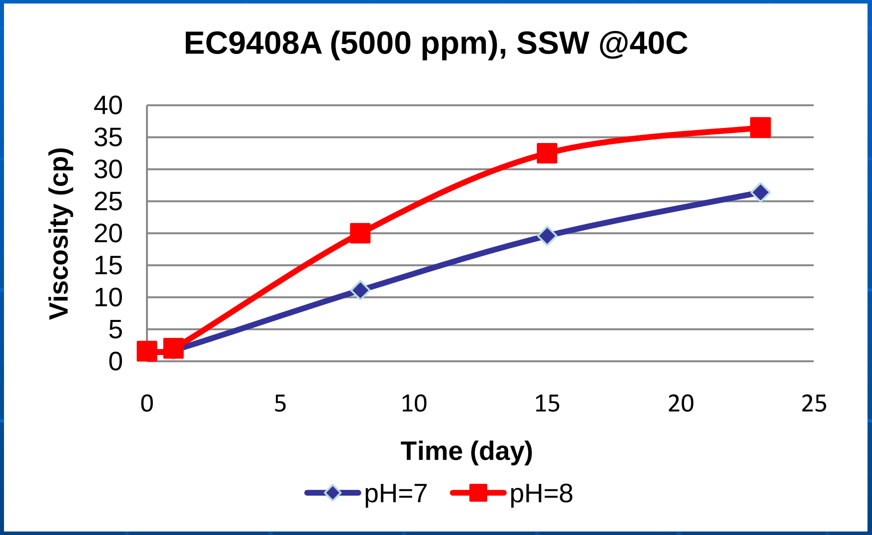
Lab tests Simulation

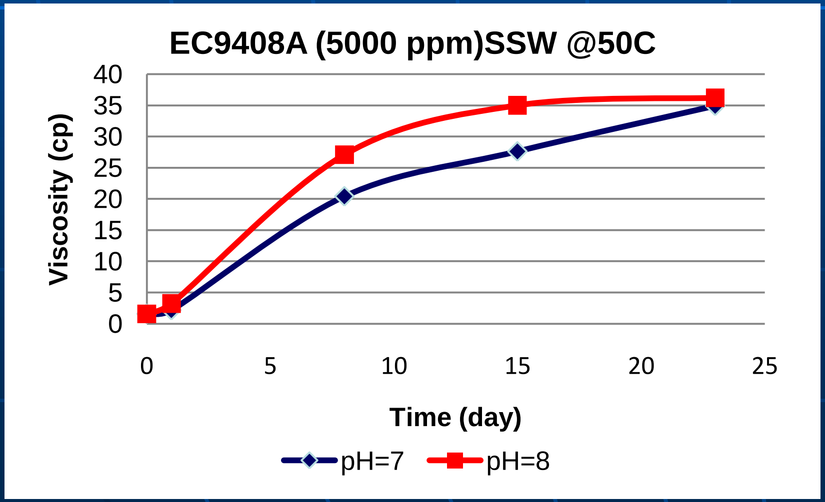
Lab Studies

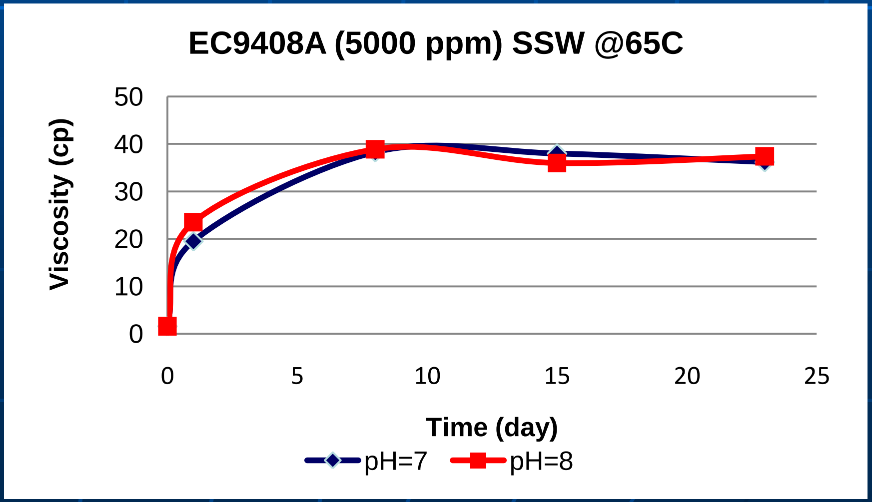
BrightWater Lab. Studies: Bottle Tests

Viscosity measured at 25°C





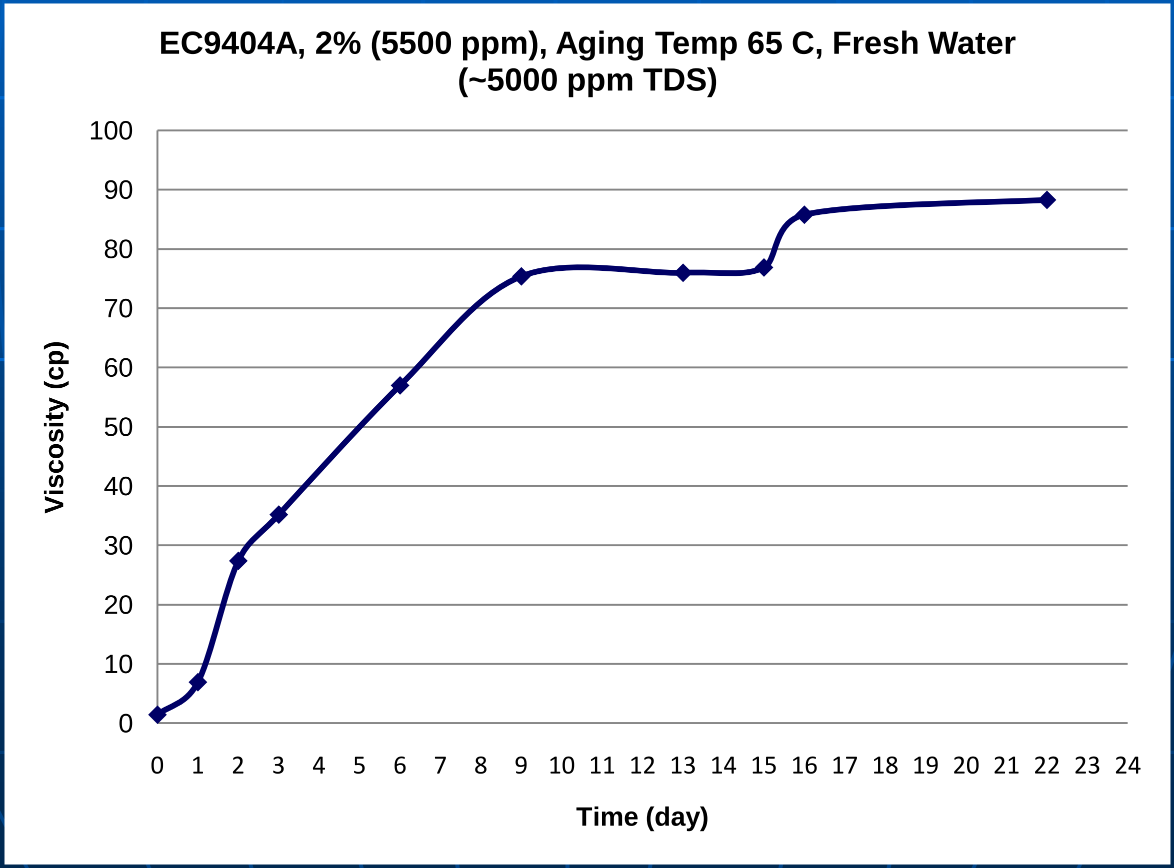




BrightWater Lab. Studies: Bottle Tests

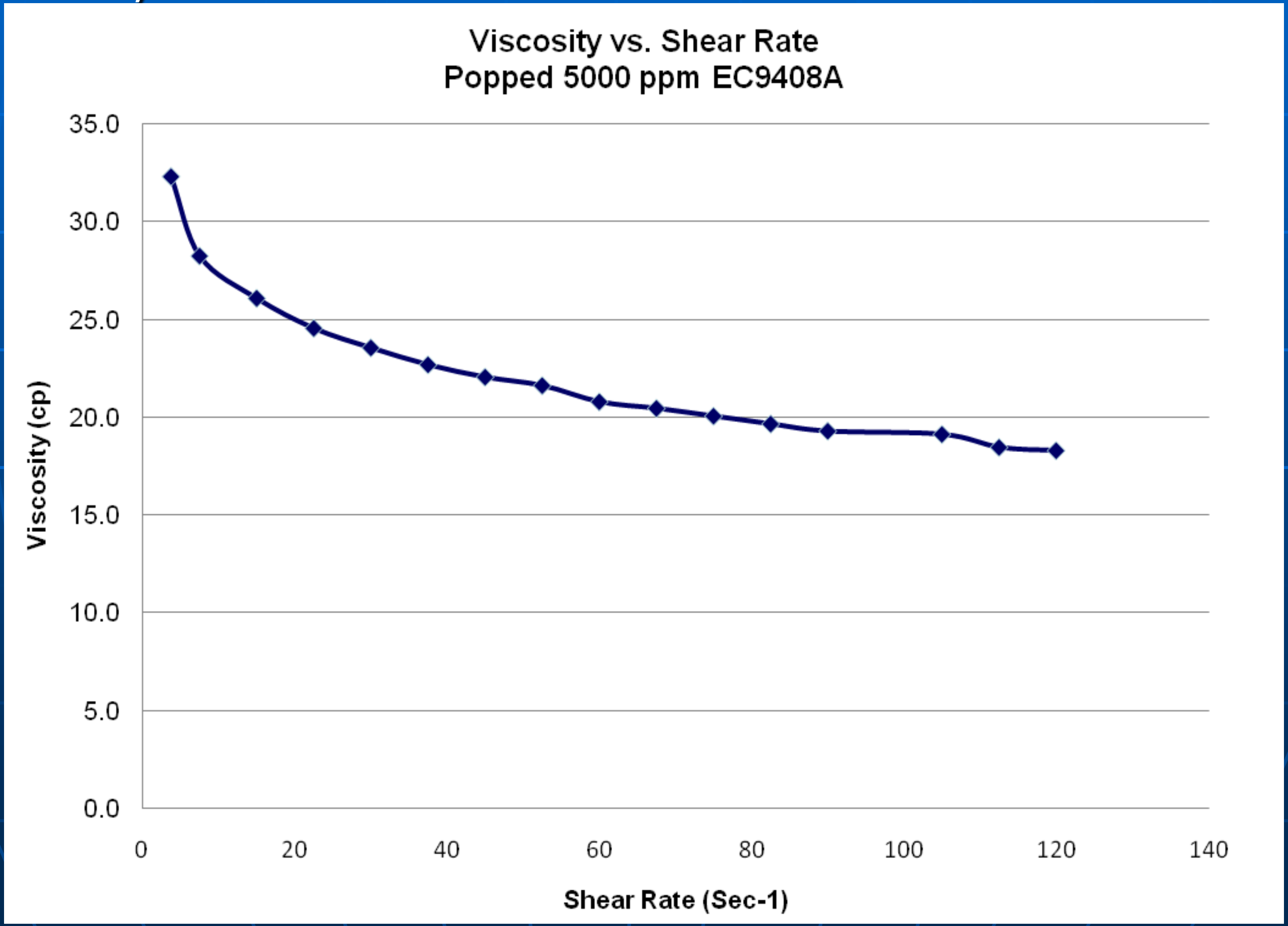
- Measure viscosity to confirm activation time and level of expansion with time and temperature

Viscosity measured at 25 °C



BrightWater Lab. Studies: Bottle Tests

- BW viscosity is sensitive to temperature, brine salinity and hardness, and shear rate

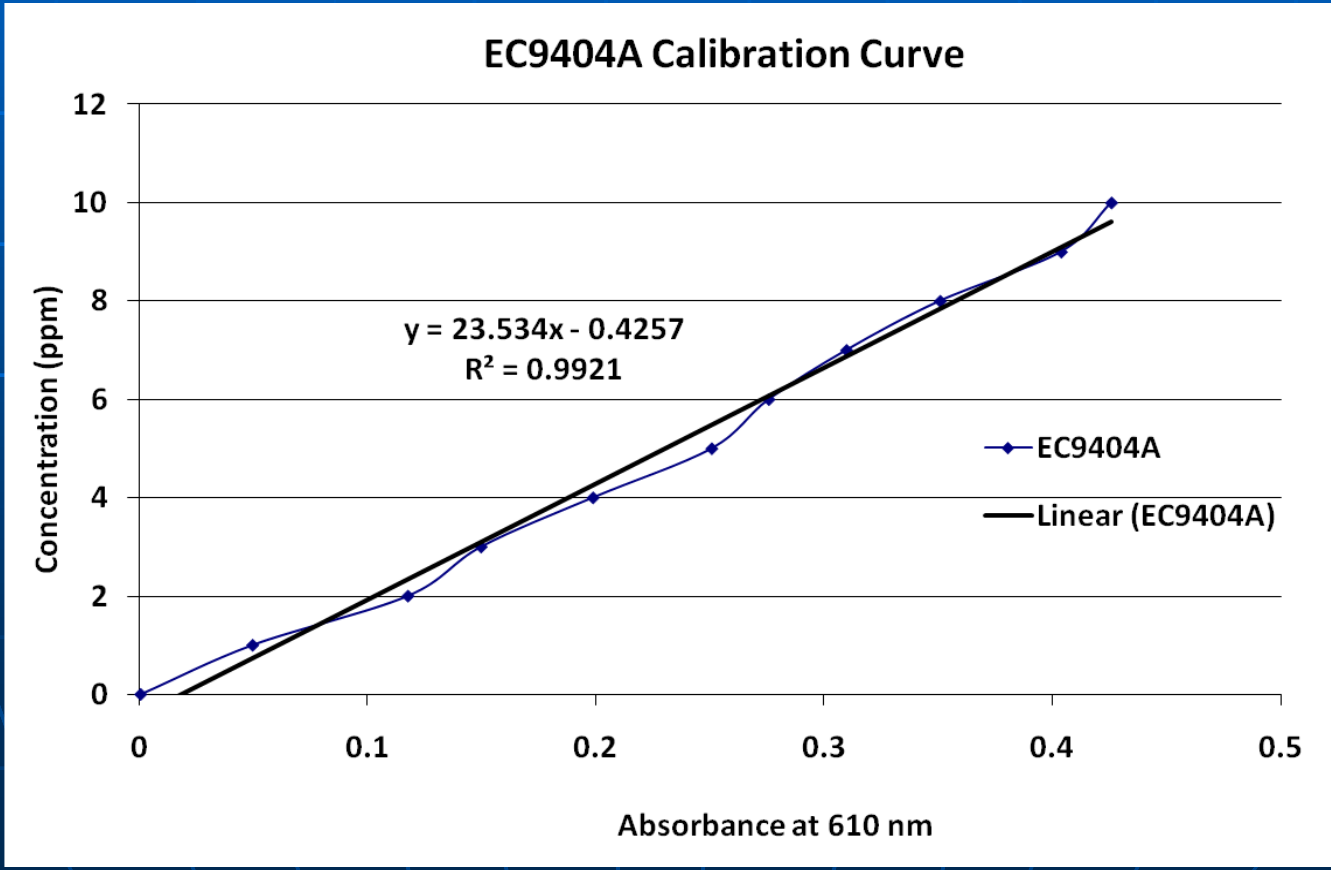


BrightWater Lab. Studies: Adsorption Tests

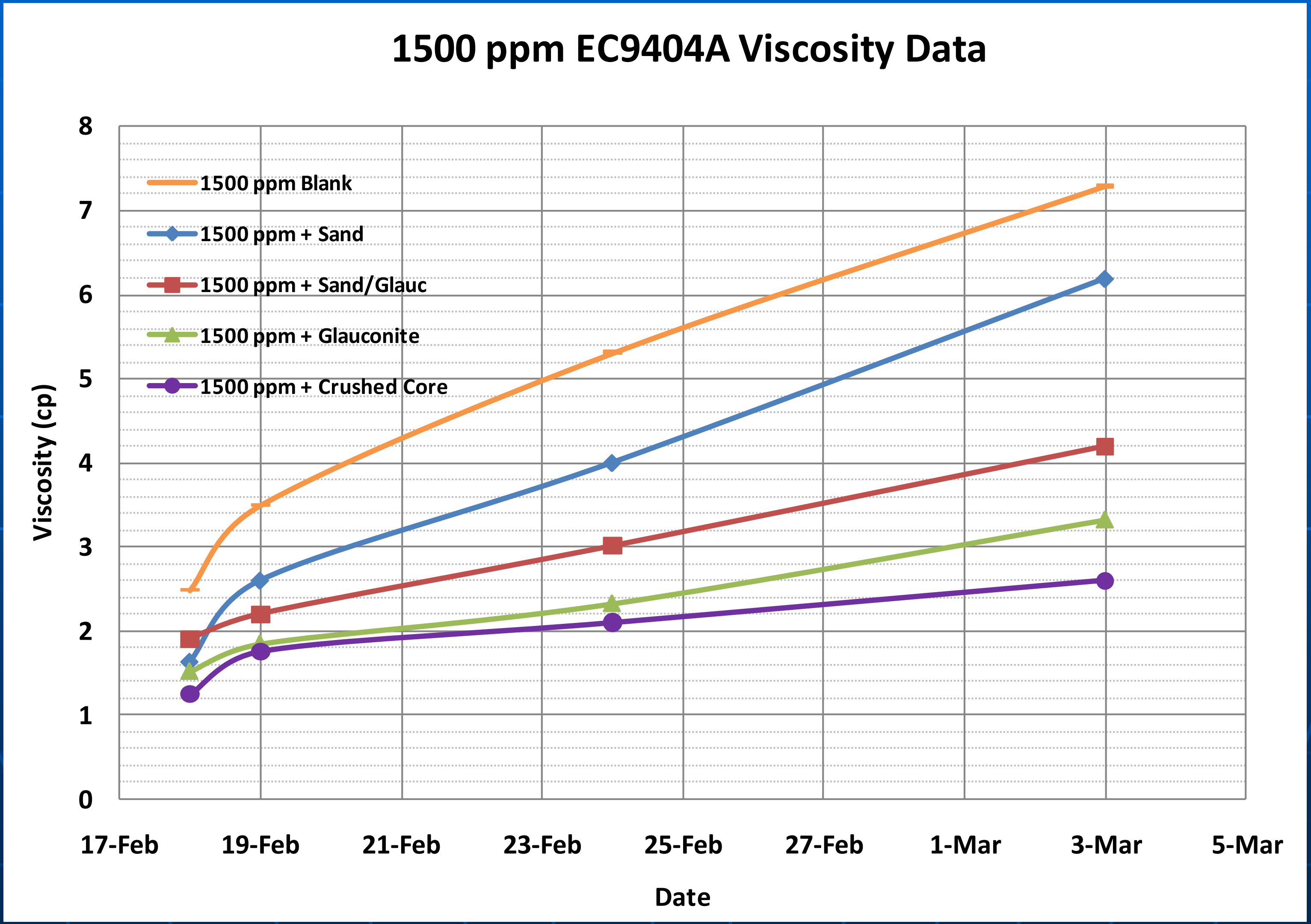
- Modified bottle tests are performed to obtain the static adsorption data for BrightWater on any media
- Solid phase will be added to the bottle in contact with BrightWater solution
- Solutions will be monitored for viscosity and concentration
- Compared with blank solutions, adsorption values are obtained using simple material balance equations

BrightWater Lab. Studies: Adsorption Tests

- Concentration of BrightWater solution is obtained by a photometric technique (Polyacrylamide-Starch-Cadmium Iodide method)



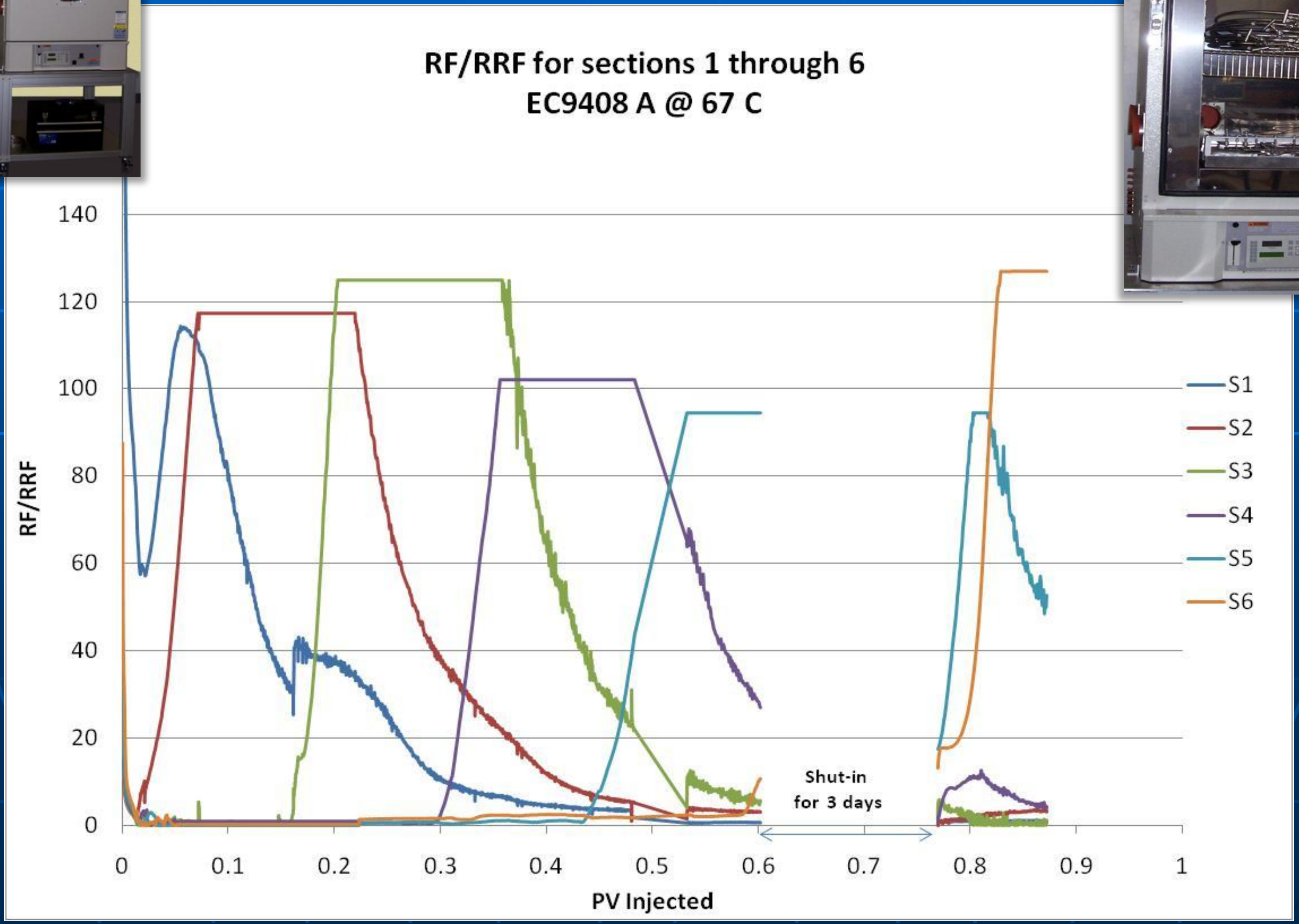
Effects of Different Rock Mineralogy on BrightWater Performance



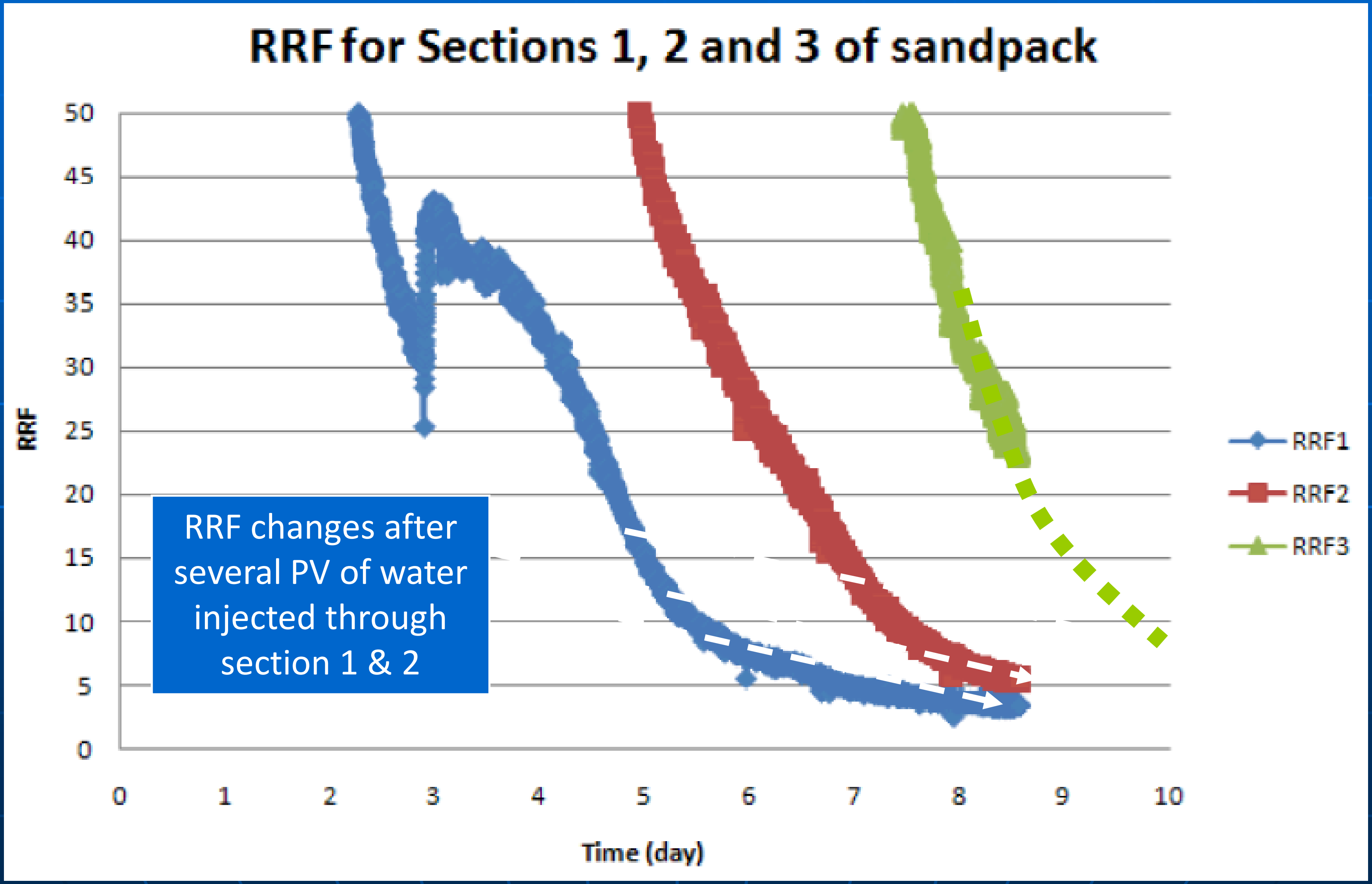
BrightWater Flow in Porous Media

- Slim tube / core flooding are performed to evaluate the BrightWater performance in porous media
- After constructing the slim tube at a representative permeability close to that of thief zone in the reservoir :
  1. Base permeability and pressure drops will be measured for each section
  2. A % PV slug of BW will be injected at high rates into the sandpack at injection temperature
  3. BW slug will be pushed through the first section of sandpack
  4. As soon as the end of the slug leaves the first section, the flow rate will be dropped to ~ 1 ft/day and the temperature will be raised to reservoir temperature
  5. Monitor for resistance and residual resistance factors

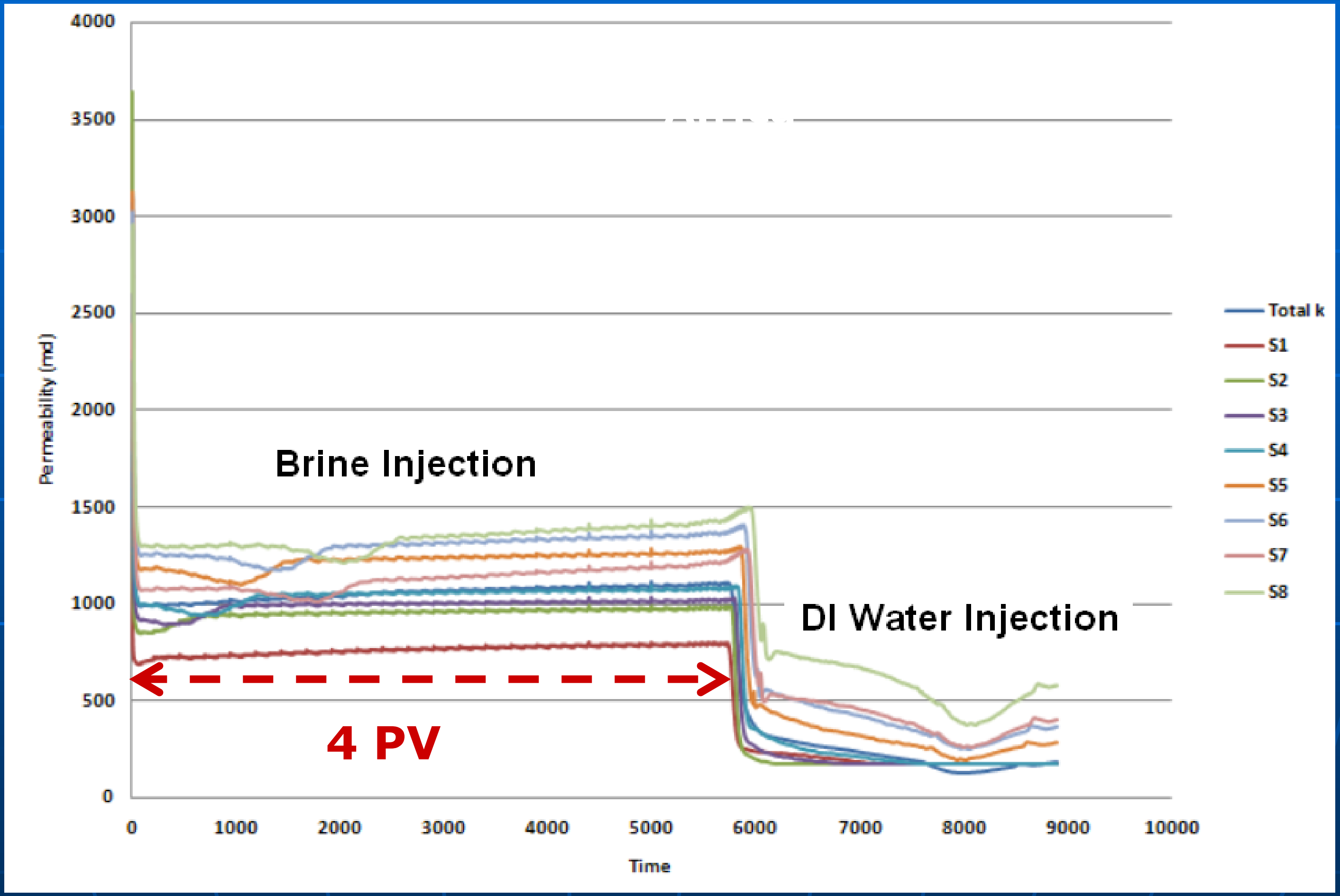
BrightWater Flow in 2 Darcy Sand Pack



Slim Tube Test Results: Interpretation (RRF Per Section)



Slim Tube Test Results: Verification of Polymer Adsorption

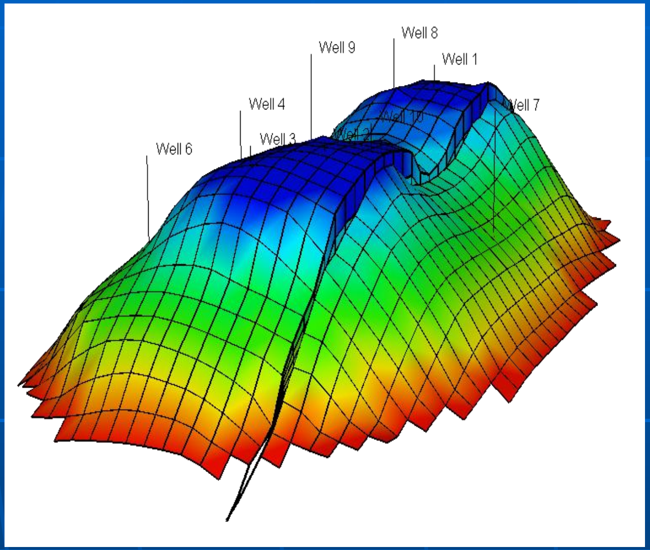


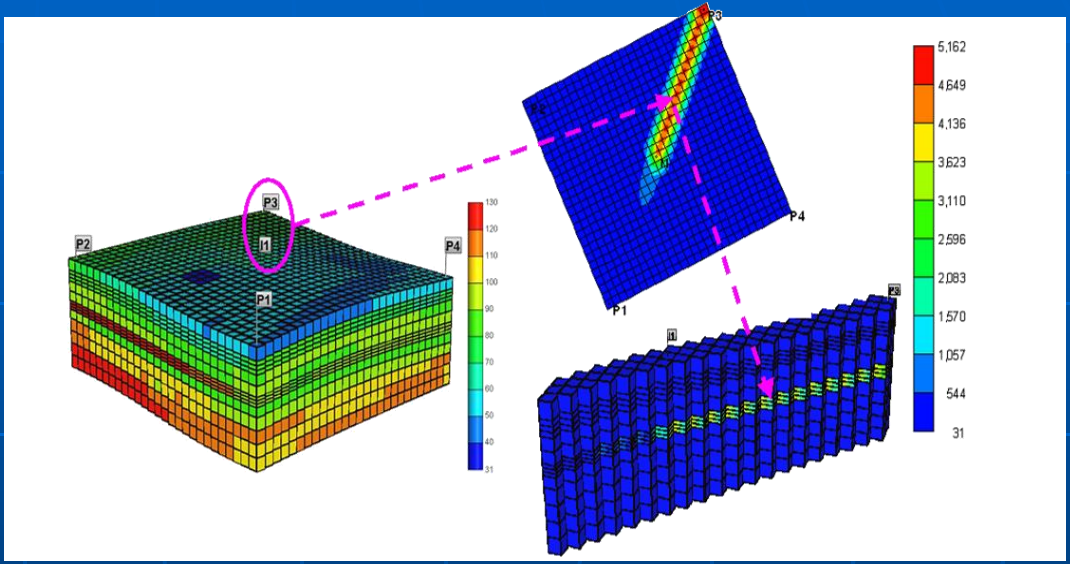
- It is known from the chemistry of polymers that they exhibit a larger viscosity in fresh water compared with high salinity waters

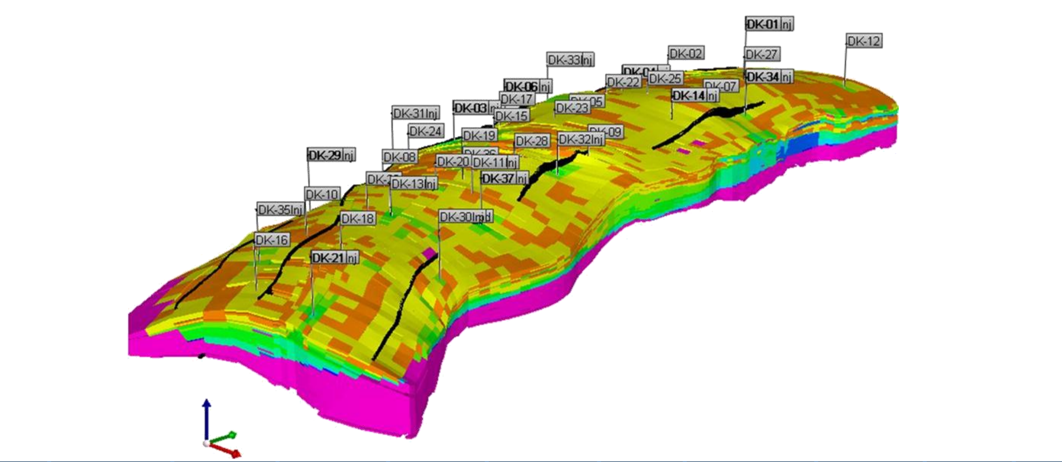
Numerical Simulation Studies

Modeling and Simulation

- Reservoir or conceptual models

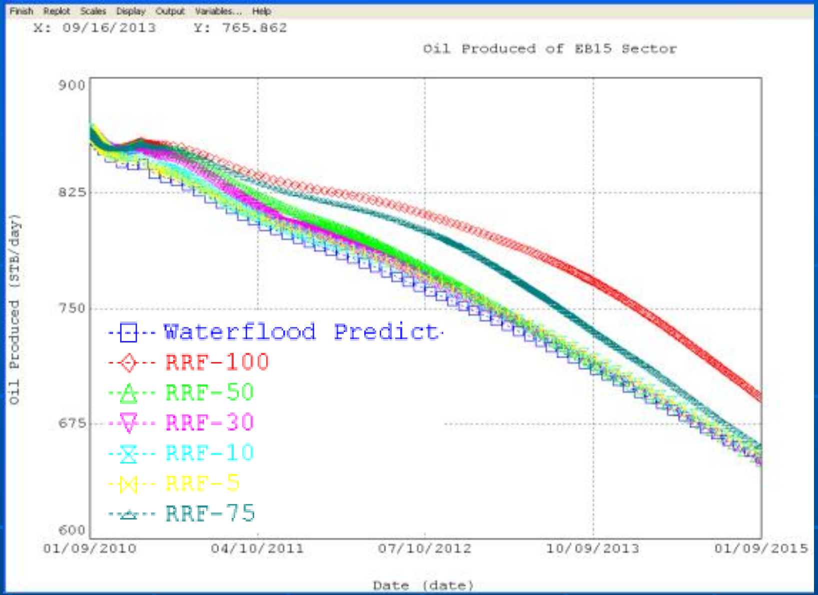


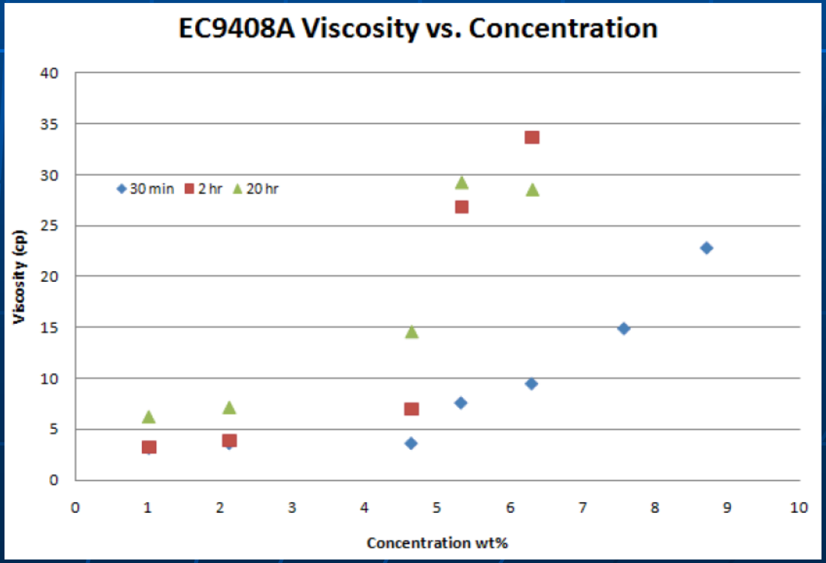




Reservoir Modeling Approach

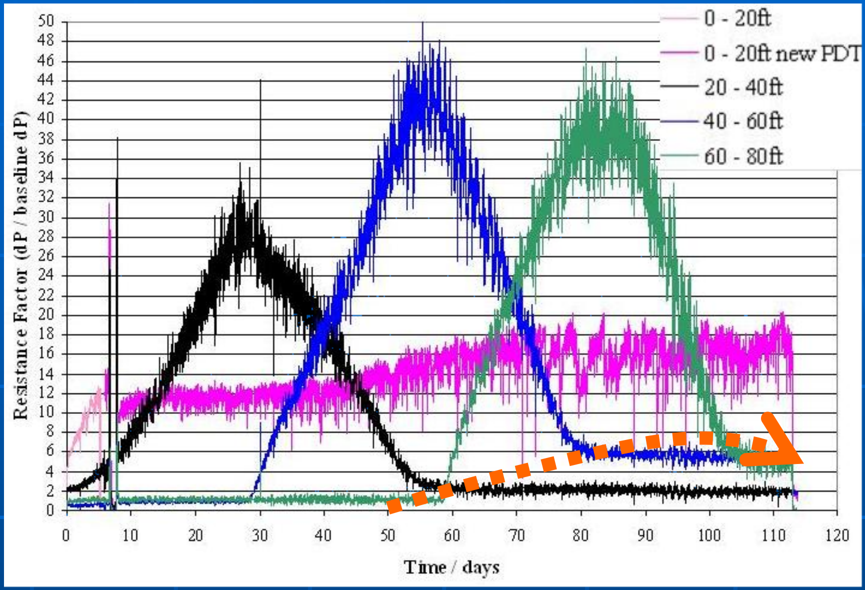
- Simple permeability (transmissibility) reduction of grid blocks based on temperature front and tracer traveling times (not moving slug between injector and producer).
- Polymer gelation as a function of temperature and time. However, gelation function (equation parameters) is not fully explicit.
- Permeability reduction is a function of gel adsorption and concentration. Possible retention, filtration and dilution effects are not necessarily considered.
- The bigger the block (permeability reduction) the higher the recovery.

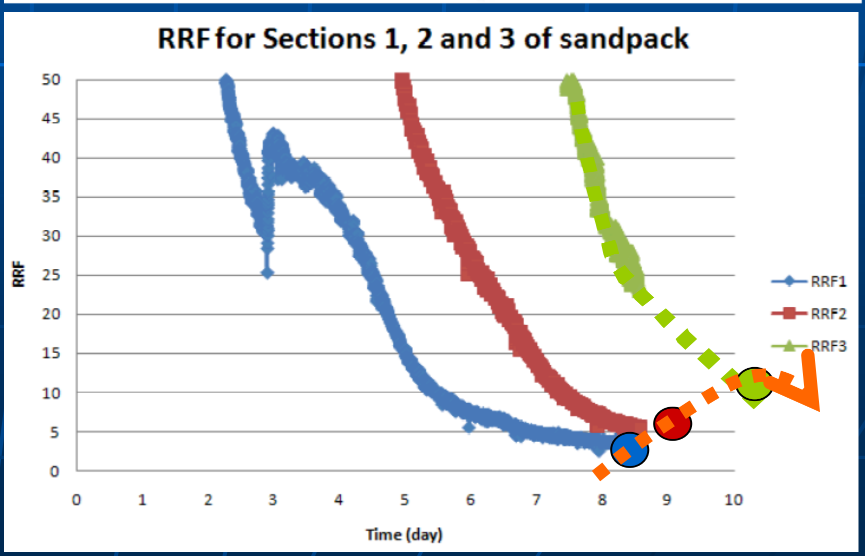




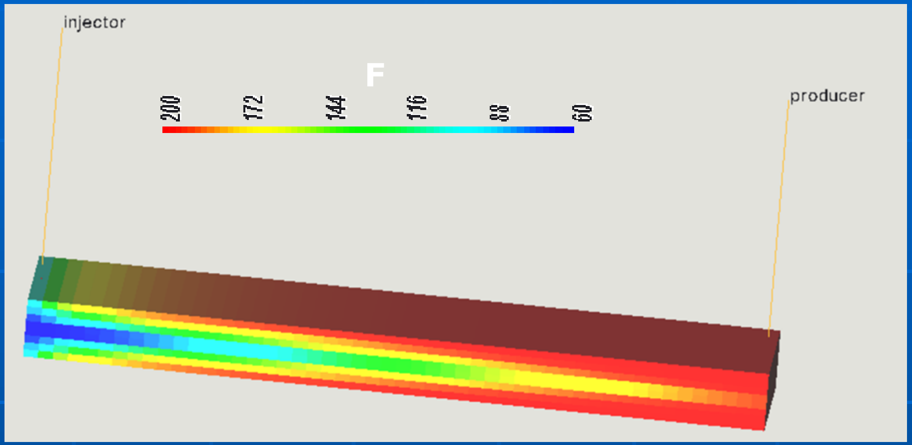
Reservoir Modeling Approach (Cont.)

- Permeability reduction / mobility control in most permeable (thief zone) layer assuming:
  - Viscous flow of BW (Like Resistance factor - RF or residual resistance factor - RRF in Polymer flooding or Colloidal Dispersion Gels - CDG's).
  - Define rock regions operating under different flow regimes (Rel. perms per region or rock type modifying water mobility). Impact of BW on oil mobility is unknown.
- Integrate thermal and chemical effects based on correlations obtained from lab data (Ongoing efforts to avoid using Restart options)

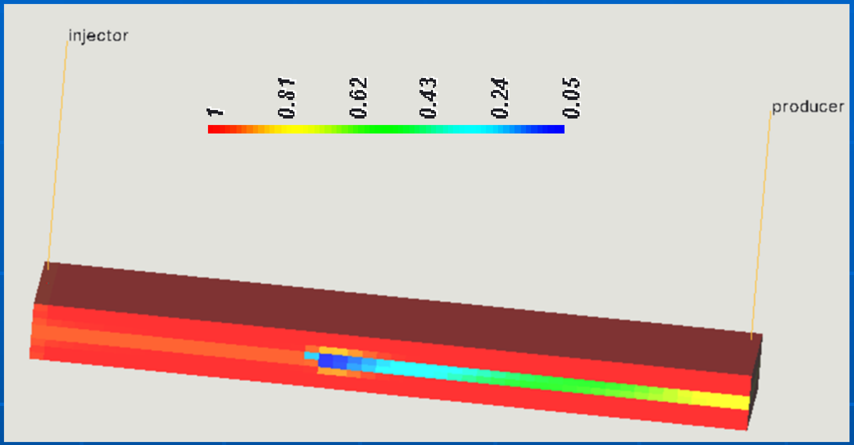




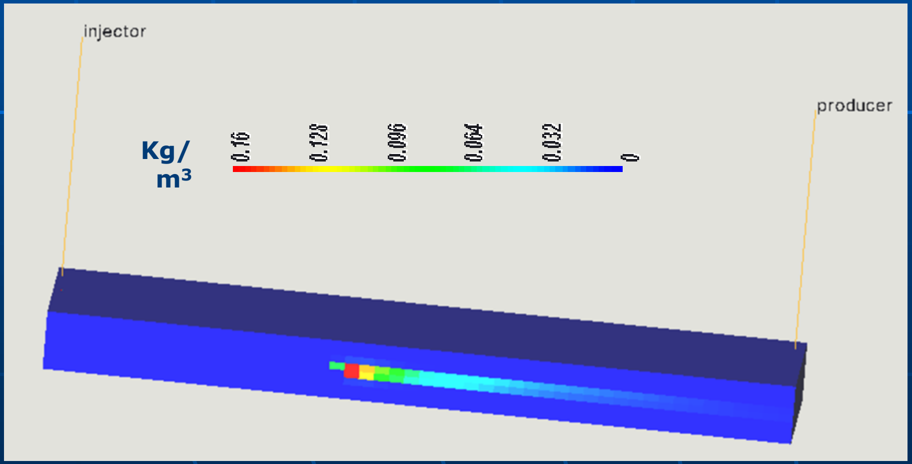
Base Case Model Results



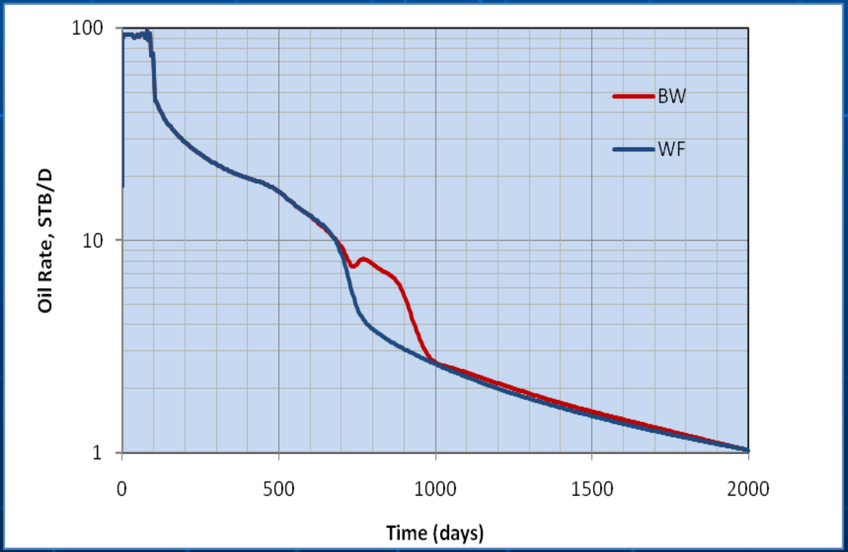
Temperature profile at the start of BW injection (t=600 days)



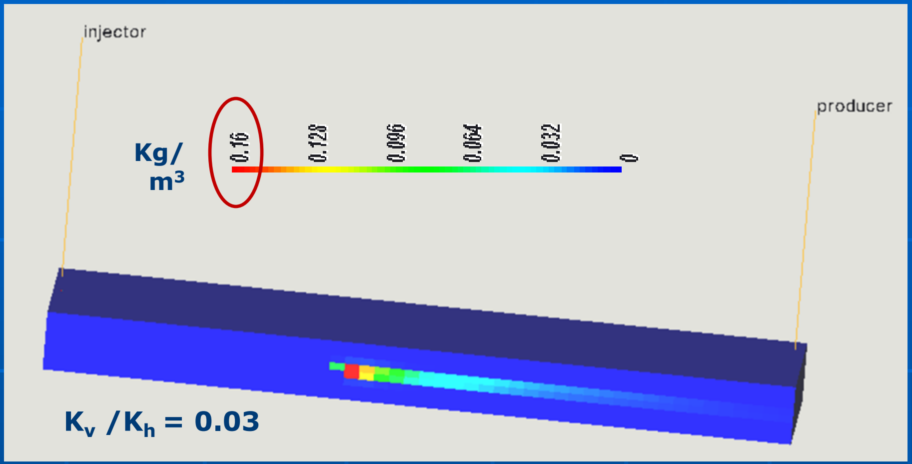
Permeability reduction factor after 300 days of BW injection (t=900

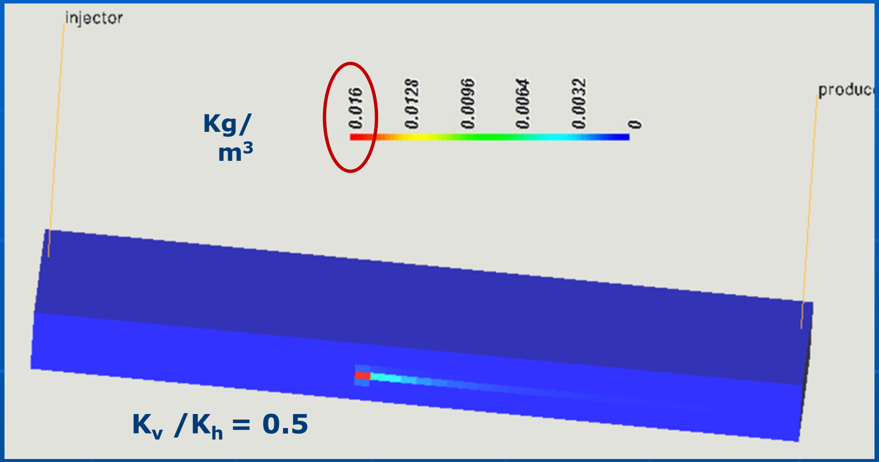


BW adsorption after 300 days of BW injection (t= 900 days)

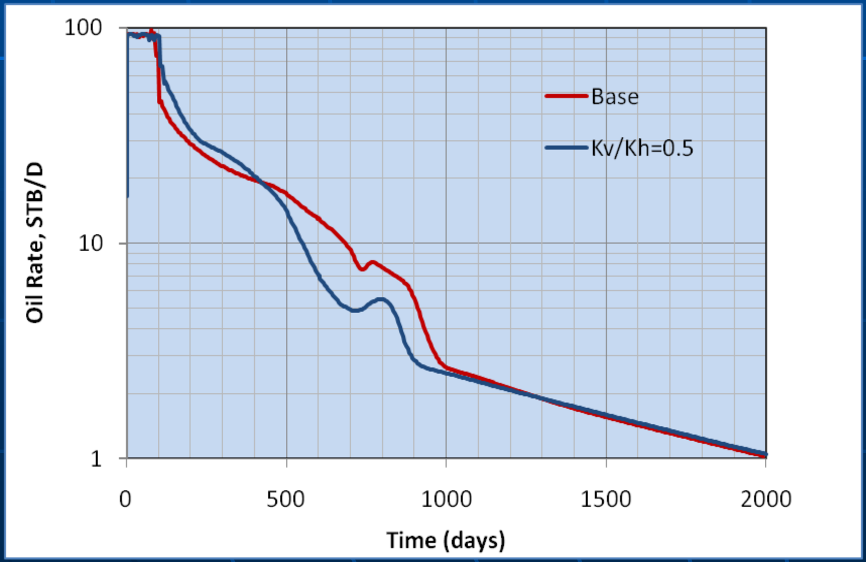


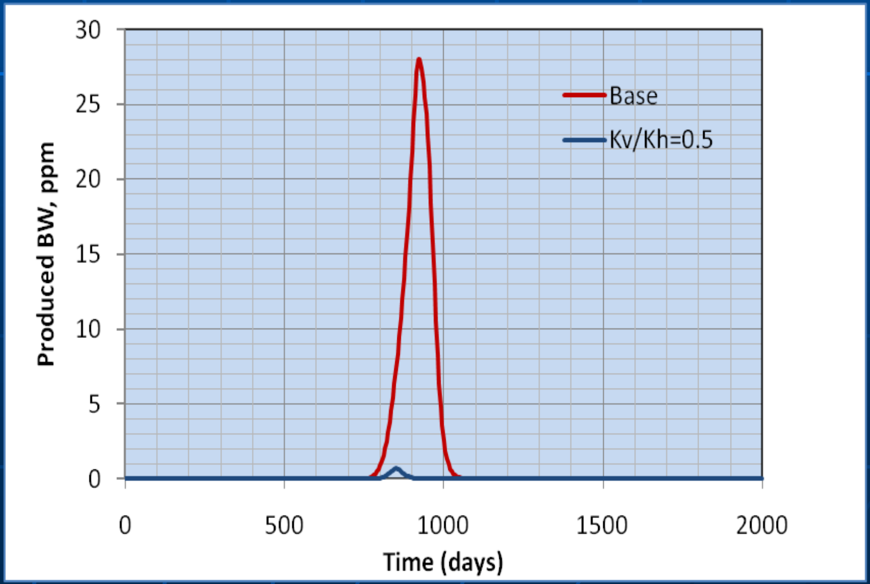
Kv/Kh Sensitivity





BW adsorption after 300 days of BW injection (t= 900 days)

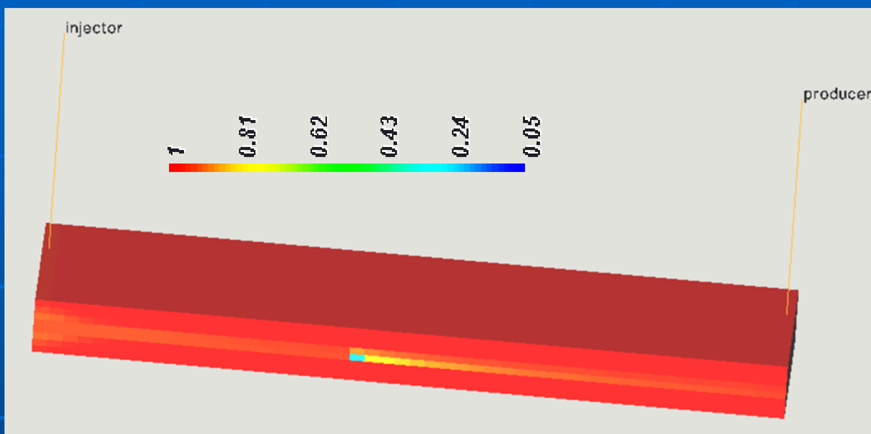


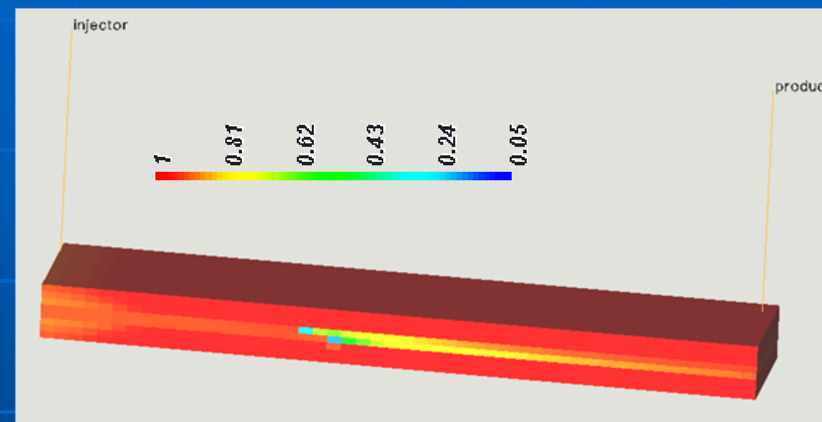


How to Improve BW effect in Reservoirs with Large kv/kh

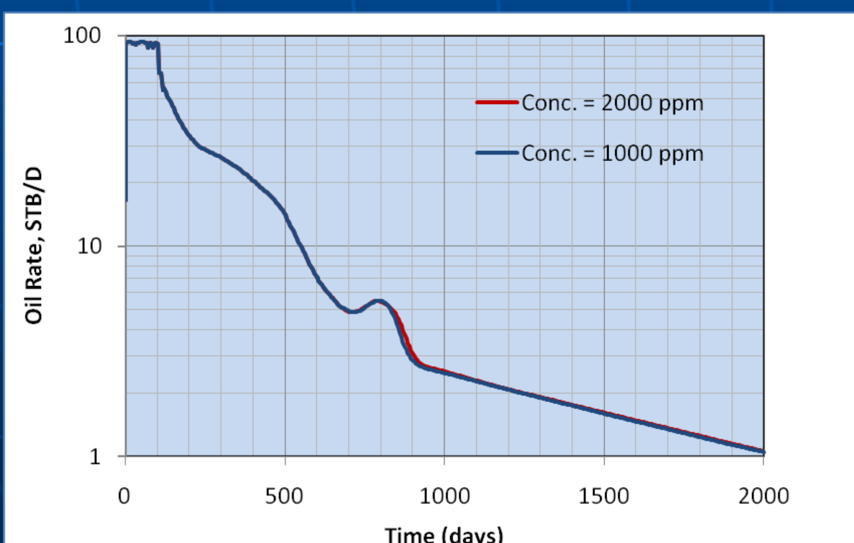
BW Conc. = 10000 Poly, 1000 CL
Kv/kh=0.5

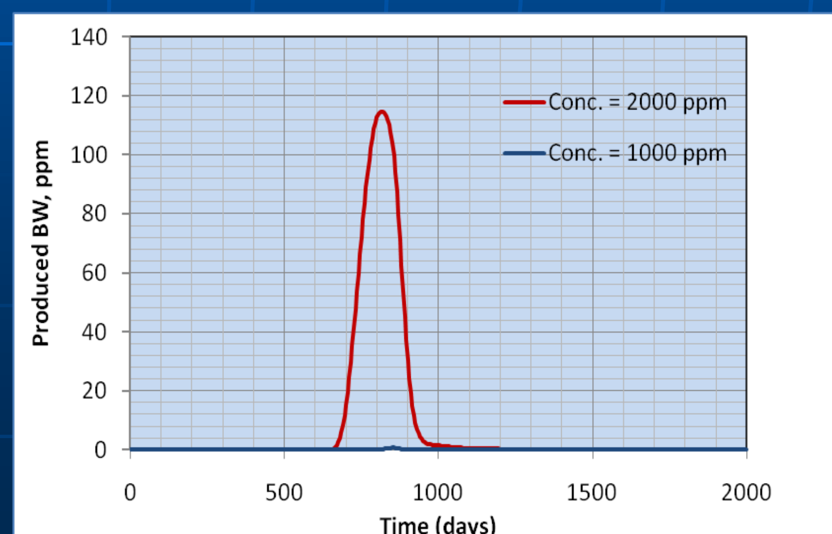
BW Conc. = 20000 Poly, 2000 CL
Kv/kh=0.5





Permeability reduction factor after 300 days of BW injection (t=900 days)





Reservoir Modeling: Sensitivity Analysis

- Common sensitivity analysis of BW performance predictions include:
  - BW concentration and treatment volumes
  - Polymer (Gel) adsorption/retention (Reversible vs. Irreversible)
  - RF and RRF
  - BW dilution effects:
    - Vertical (wellhead vs. selective Injection)
    - Volumetrically (within the thief zone – Up-scaling effects)
  - Temperature profile (early vs. late BW expansion)
  - Kv/Kh
  - Injection/production rates (e.g. impact of BHP)

- Validate BW treatment design against reservoir performance (history match BW test) to identify key tuning parameters