SPE 100082

Optimization of Chemical Flooding in a Mixed-Wet Dolomite Reservoir

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2006 SPE/DOE Symposium on Improved Oil Recovery

Tulsa, Oklahoma • April 22-26, 2006

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Acknowledgements

- Department of Energy
  - Grant: DE-FC26-04NT15529
  - Grant: DE-FC26-03NT15406
- Oxy Permian

Presentation Outline

- Introduction
- Overview of reservoir
- Simulation model development
- Base case surfactant/polymer (S/P) design
- Design optimization using sensitivity analysis
- Design uncertainty
- Conclusions

Introduction

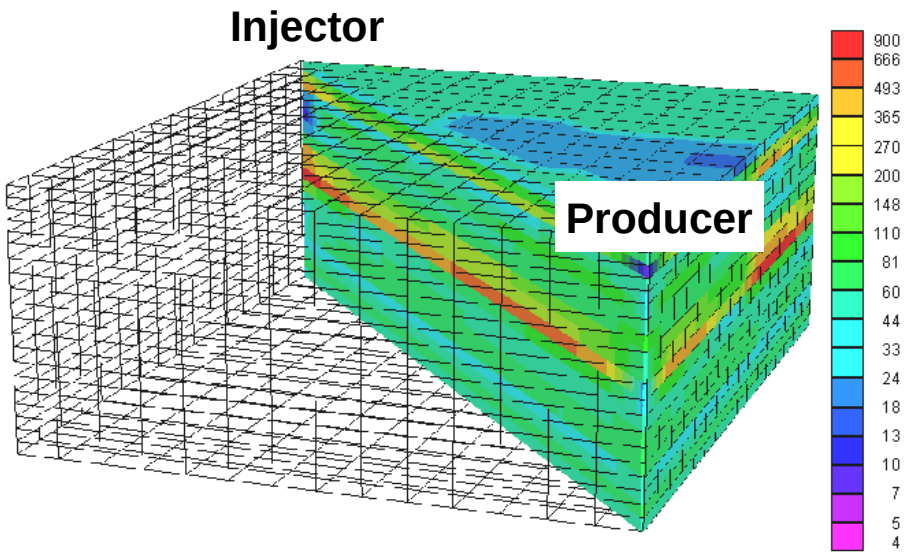
- Past chemical floods in sandstones
  - Water-wet
- Carbonate reservoirs are complex
  - Mixed-wet and oil-wet
  - Few chemical floods in carbonates
- Objective of this study
  - Optimize an S/P design for a mixed-wet carbonate
  - Sensitivity and economic analyses

Reservoir Overview

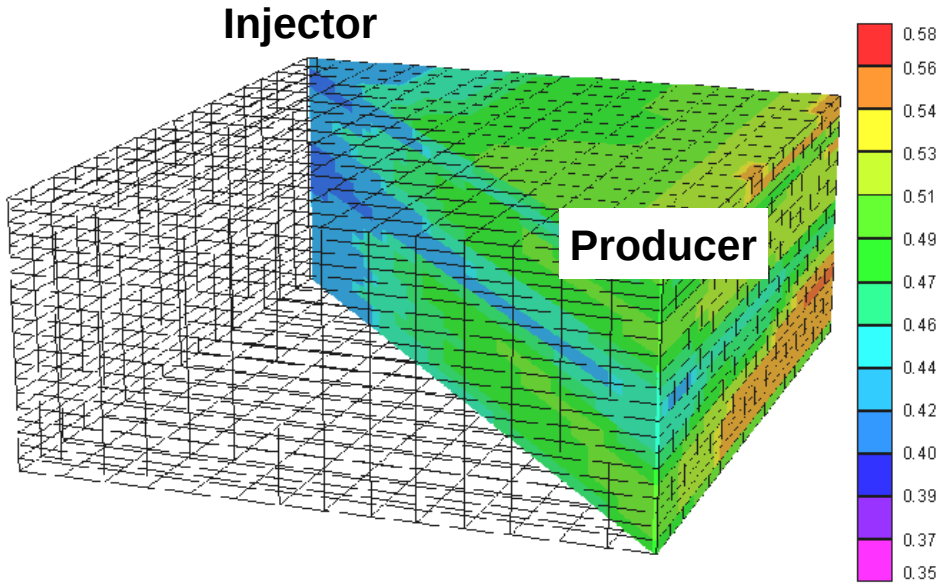
- West Texas Field (Permian Basin)
  - Mixed-wet dolomite within Grayburg
  - Highly heterogeneous with layering
  - Primary recovery – 10% OOIP
  - Secondary recovery – 15% OOIP
  - Depth of 4,700 ft
  - Low reservoir pressure (~750-1000 psi)
  - High residual oil saturation (~40%)
  - Currently waterflooding 40-acre 5-spot patterns
    - Producing at 1-2% oil cut

Simulation Model Development

- Using field and laboratory data
  - ¼ 5-spot symmetry element
  - 1.8 PV waterflood was simulated to obtain initial conditions



Permeability (md)



Post-Waterflood Oil Saturation

Base Case S/P Design

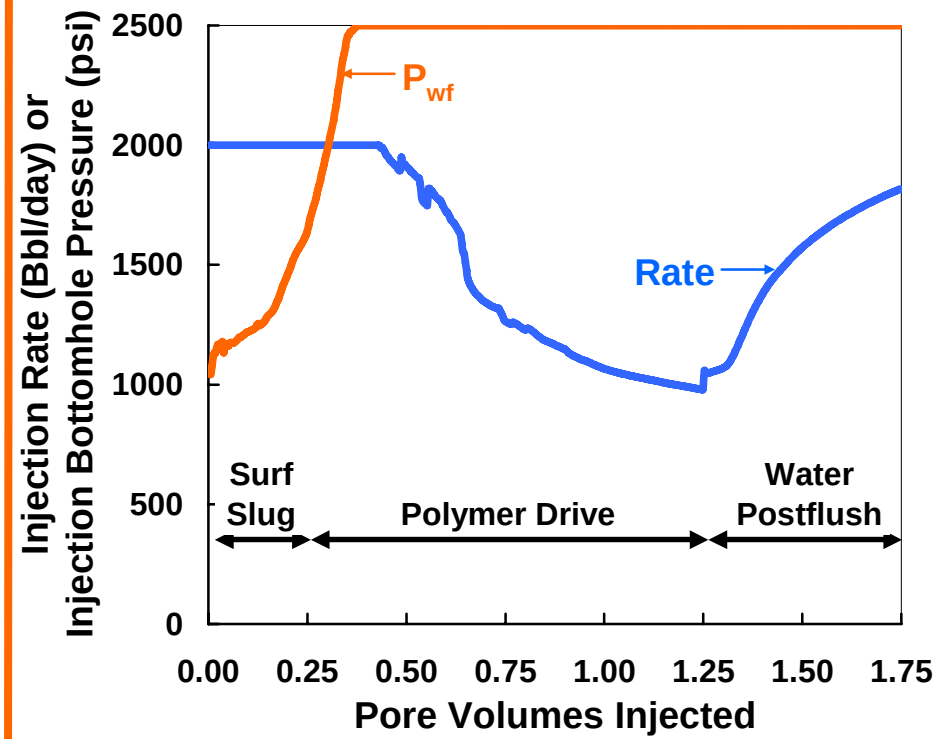
Base Case Design Variables	
Injection well constraints	Rate constraint = 2,000 bbl/day Pressure control = 2,500 psi
Production well constraint	Pressure constraint = 300 psi
Surfactant slug	0.25 PV 1 vol% surfactant mixture 1,000 ppm polymer 0.365 meq/mL (21,000 ppm TDS)
Polymer drive	1 PV 1,000 ppm polymer 0.2 meq/mL (11,700 ppm TDS)
Water postflush	0.5 PV 0.04 meq/mL (2,300 ppm TDS)
Surfactant adsorption	0.3 mg surfactant/g rock

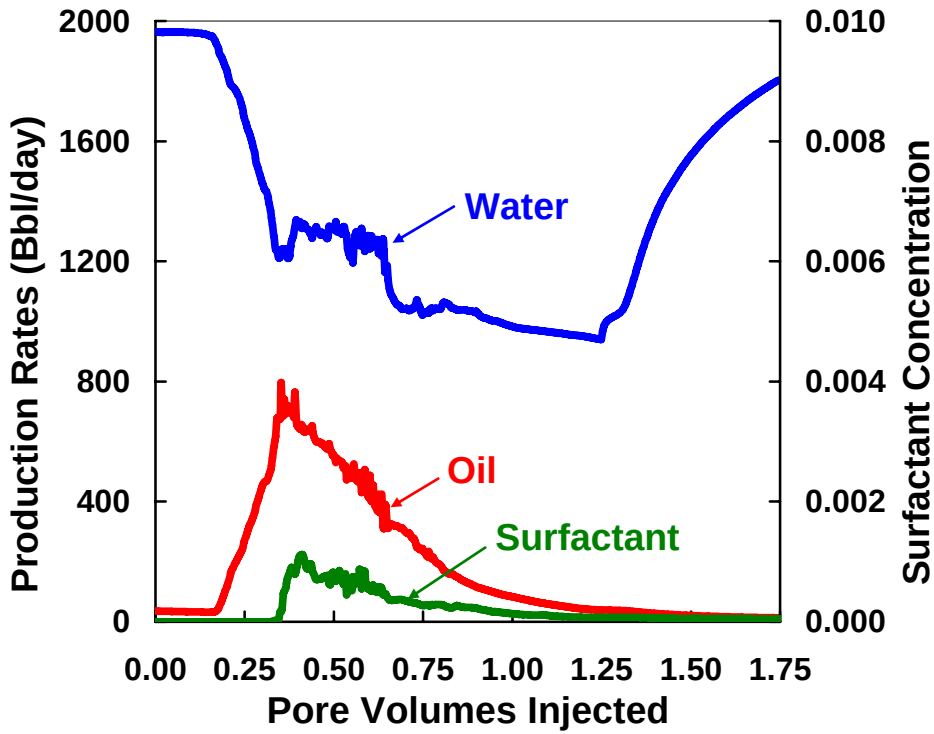
Base Case Design Assumptions	
Polymer adsorption	10 μg polymer/g rock
Capillary desaturation parameters	Water = 1,865 Oil = 59,074
Vertical permeability	$k_v/k_h = 0.05$
Permeability	156 md

For surfactant information, refer to SPE 100089

Base Case S/P Simulation Results

- 27.8% OOIP (42% ROIP)
- 21 years simulated
- $14.50 per barrel of oil
- 35 to 720 bopd





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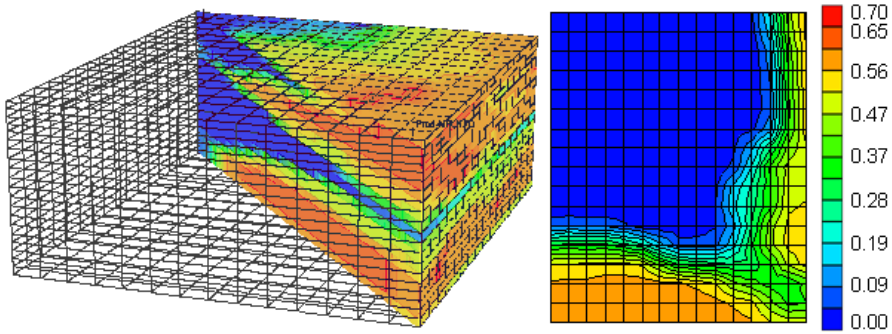
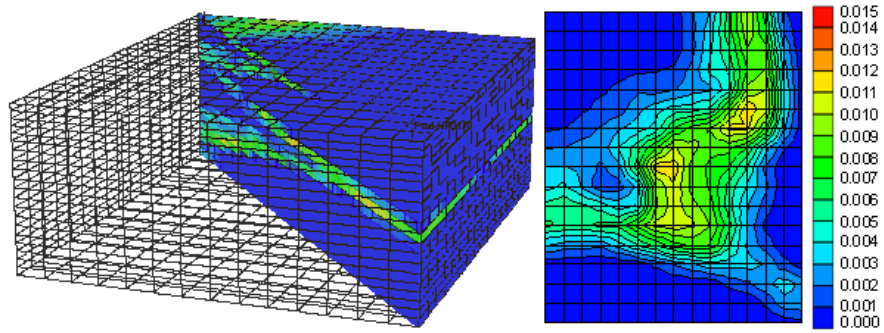
Base Case S/P Simulation Results

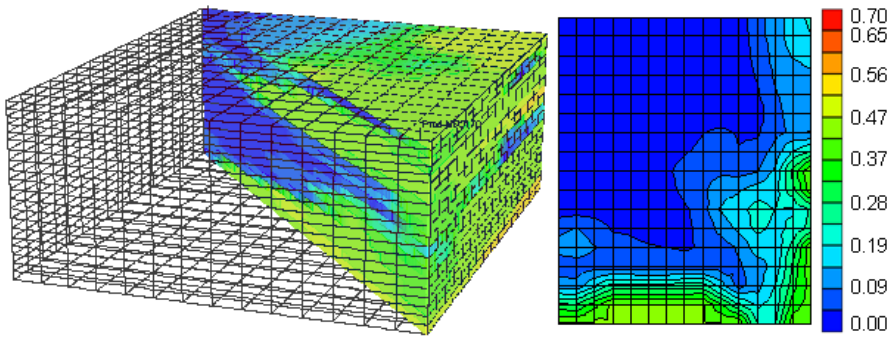
Oil Saturation
at 0.35 PV Injected



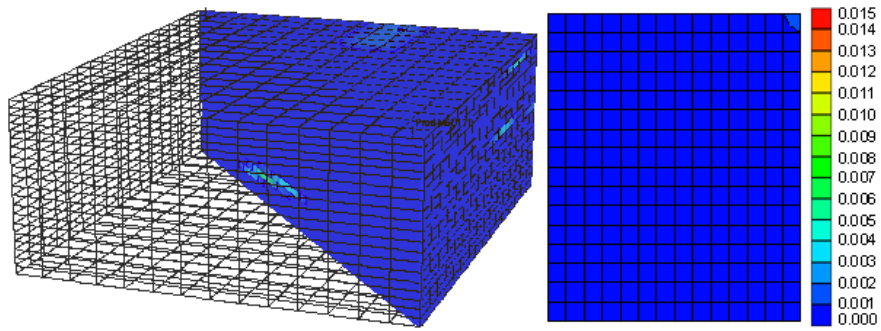
Surfactant Concentration (vol frac)
at 0.35 PV Injected



Oil Saturation
at 1.75 PV Injected (Final)



Surfactant Concentration (vol frac)
at 1.75 PV Injected (Final)



Sensitivity Analysis

- Purpose of sensitivity analysis: design optimization using key variables
- Purpose of uncertainty analysis: effect of most uncertain variables

- Key design variables
  - Surfactant concentration
  - Surfactant slug size
  - Polymer concentration
  - Polymer drive design
  - Salinity gradient

- Uncertain variables
  - Surfactant adsorption
  - Polymer adsorption
  - k_v/k_h
  - Permeability

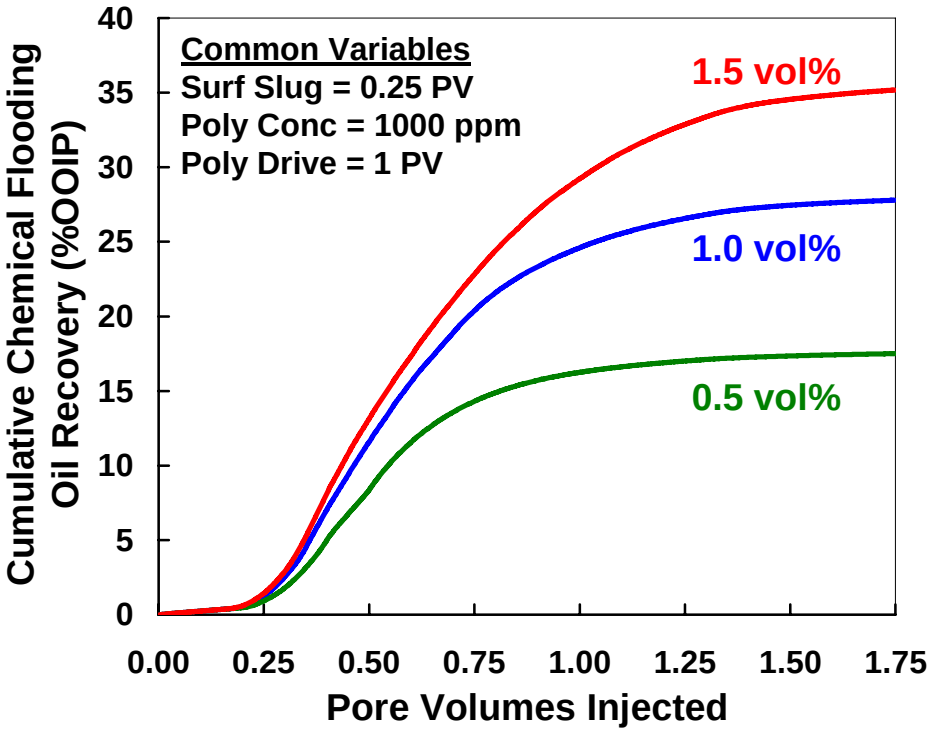
Economic Analysis

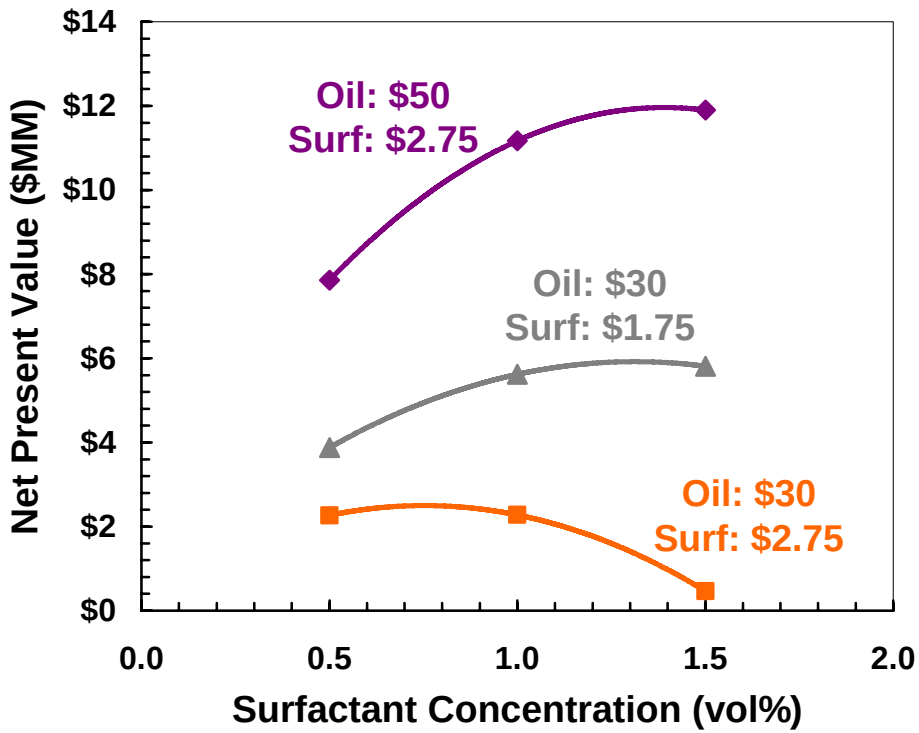
- Discounted cash flow analysis
  - Importance of chemical mass, oil breakthrough time, and project life
  - Optimum design has the highest net present value

Capital and Operating Costs	Equipment Cost	$100,000
	Operating Cost	$5,000 per month
	Chemical Injection Cost	$0.10 per barrel
	Fluid Treatment Cost	$0.10 per barrel
Oil and Chemical Prices	Oil Price	$30 - $50 per barrel
	Blended Surfactant Price	$1.75 - $2.75 per pound
	Polymer Price	$1.00 per pound
Taxation Rates	Royalty	0%
	Severance & Ad valorem	5%
	Income Tax	36.64%
	Tax Credit	15%
General Rates	Inflation Rate	3%
	Real Discount Rate	10%

Surfactant Concentration Sensitivity

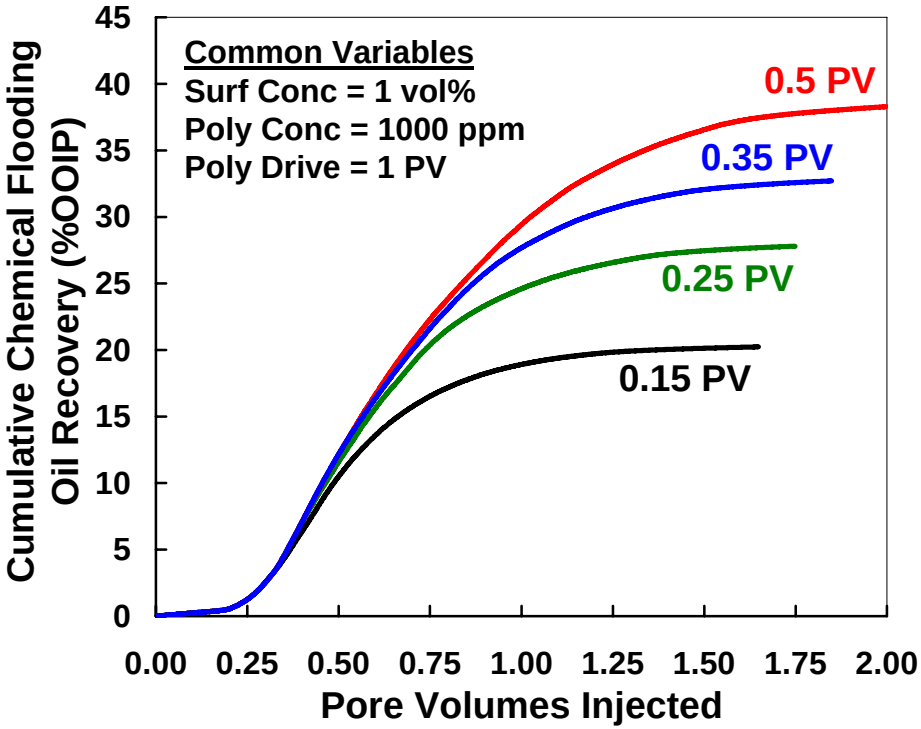
- **Surfactant concentration varied from 0.5 to 1.5 vol%**
- **Average economic limit = 16 years**

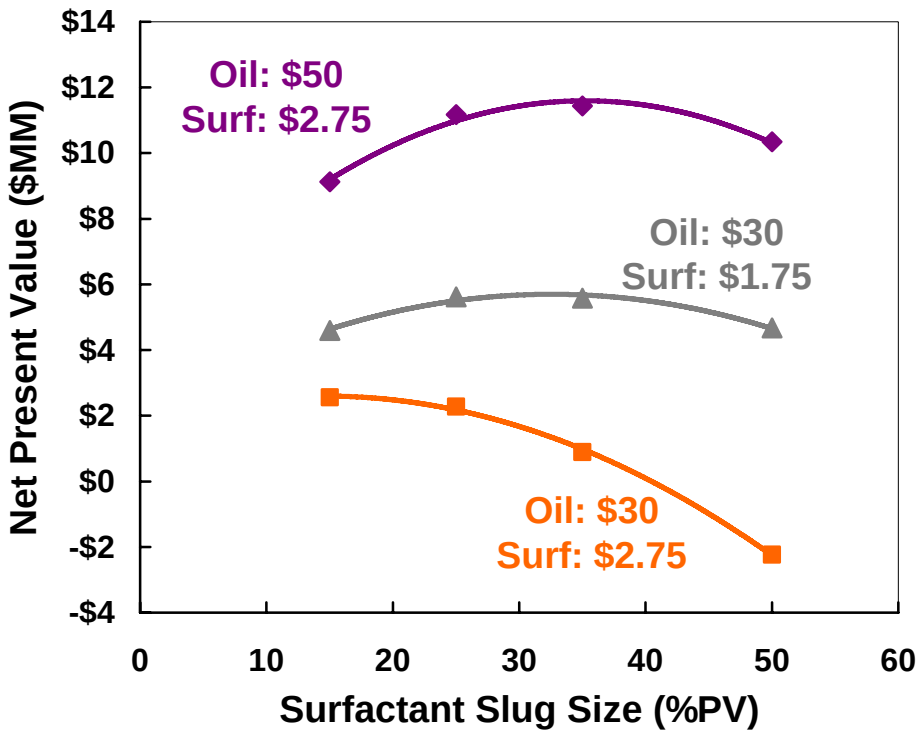




Surfactant Slug Size Sensitivity

- Surfactant slug size varied from 0.15 to 0.5 PV
- Average economic limit = 16 years





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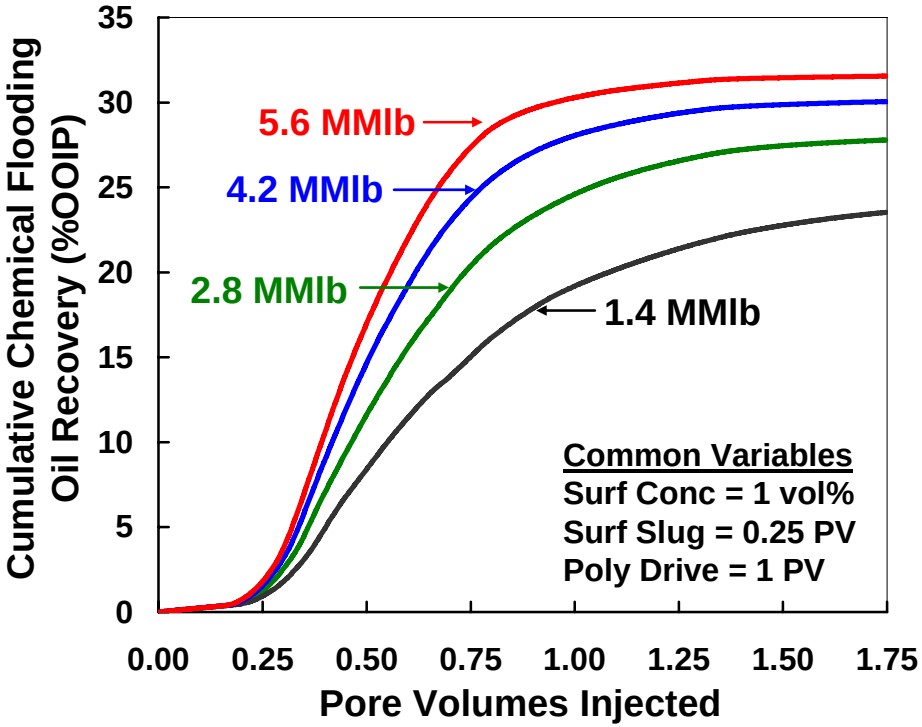
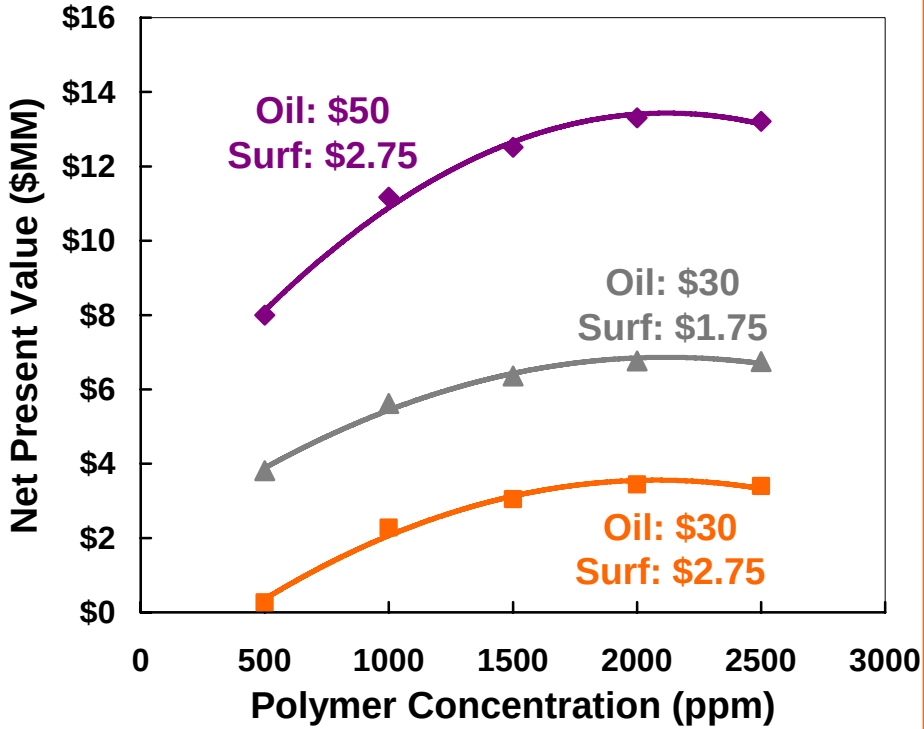
Polymer Concentration Sensitivity

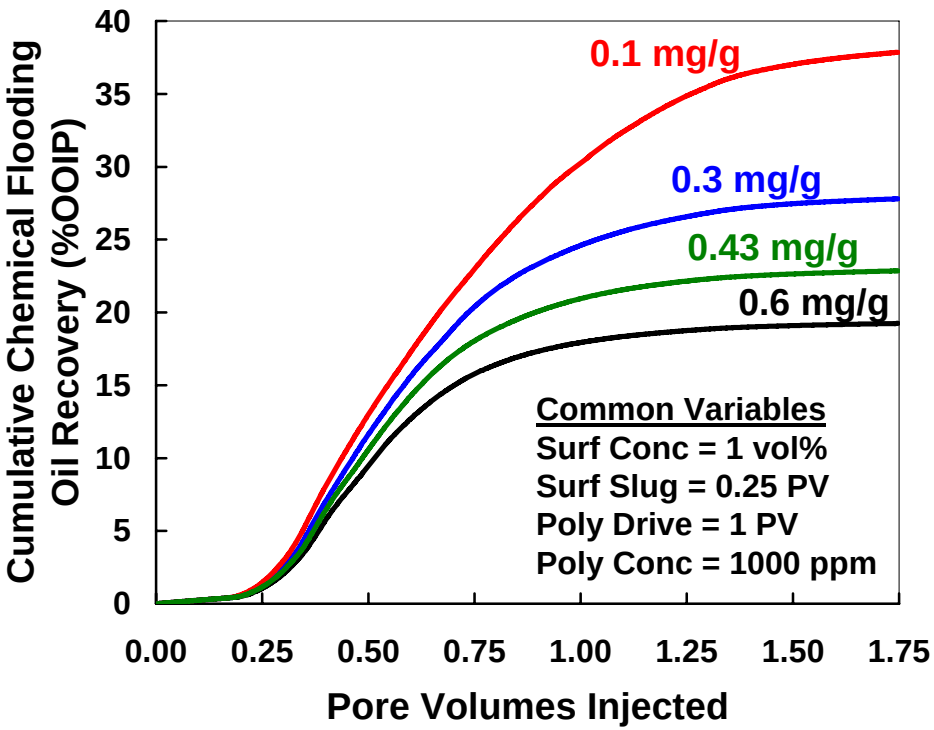
- Polymer concentration varied from 500 to 2500 ppm
- Average economic limit = 15 years

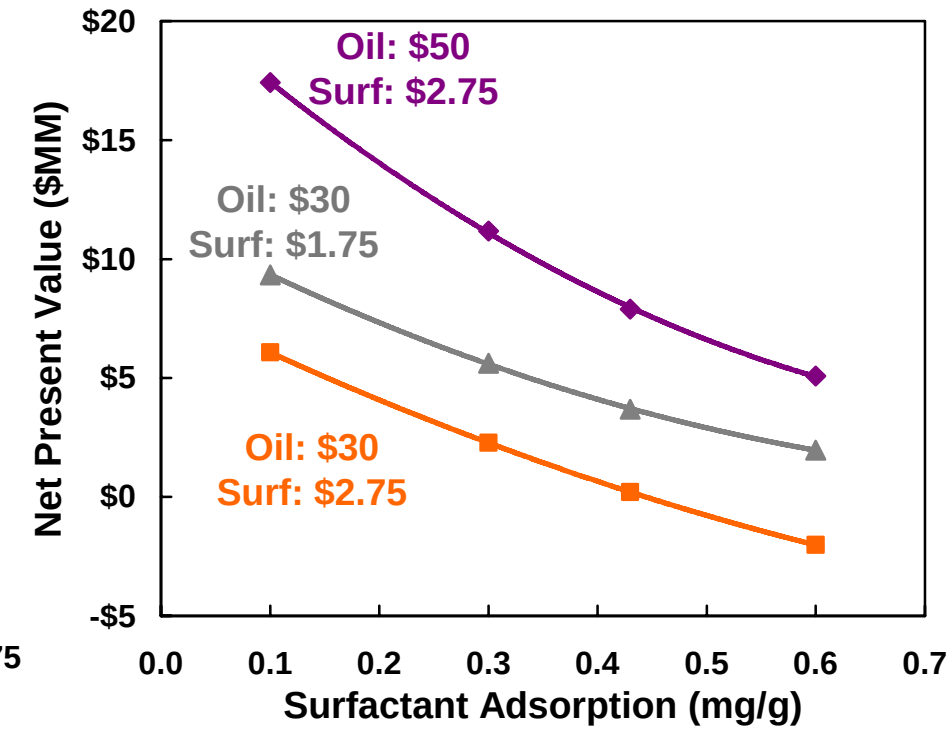




Surfactant Adsorption Sensitivity

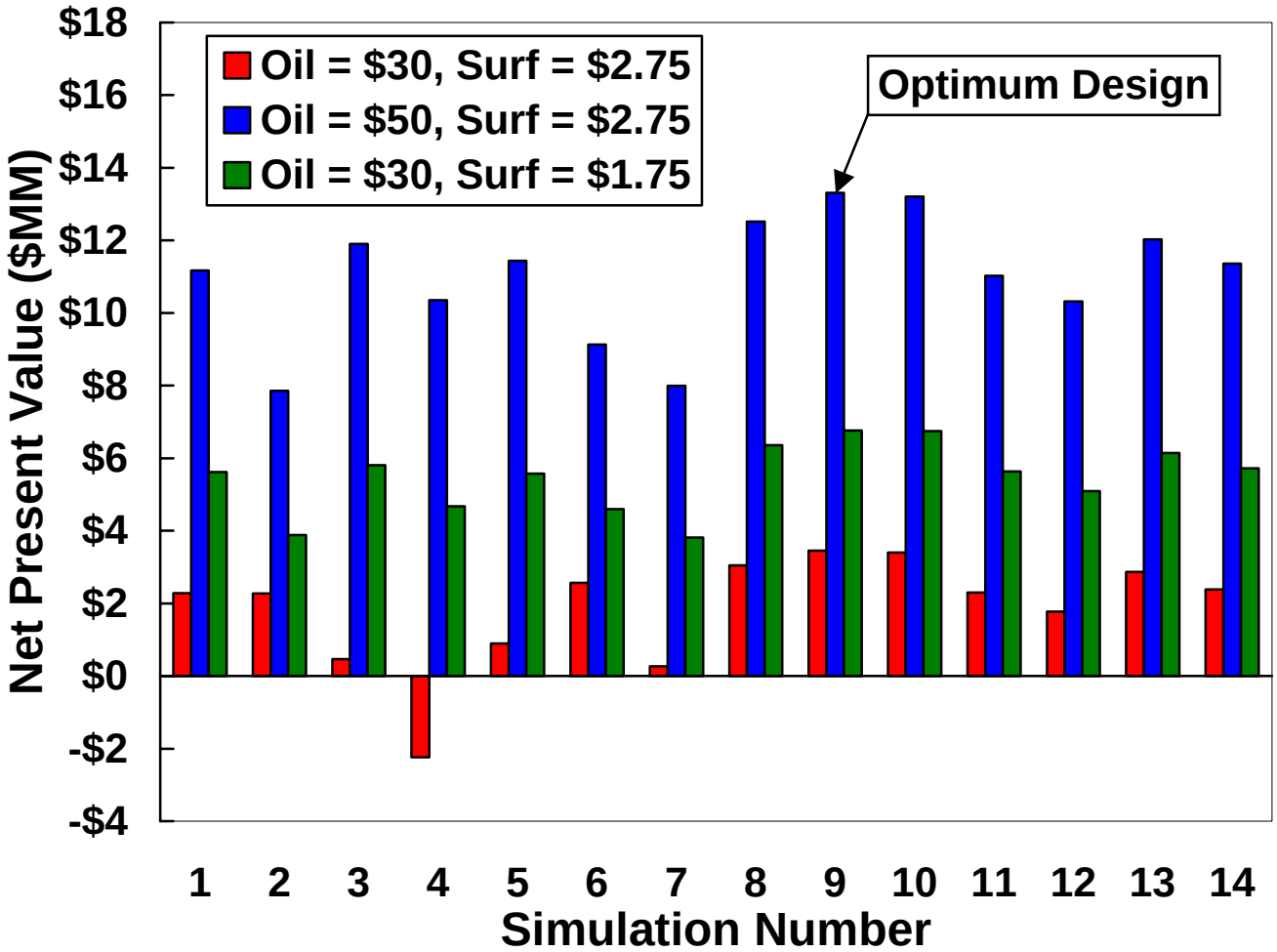
- Surfactant adsorption varied from 0.1 to 0.6 mg surfactant/g rock
- Most recent laboratory data suggest 0.1 mg/g





Design Optimization Results

Optimum design – higher polymer concentration



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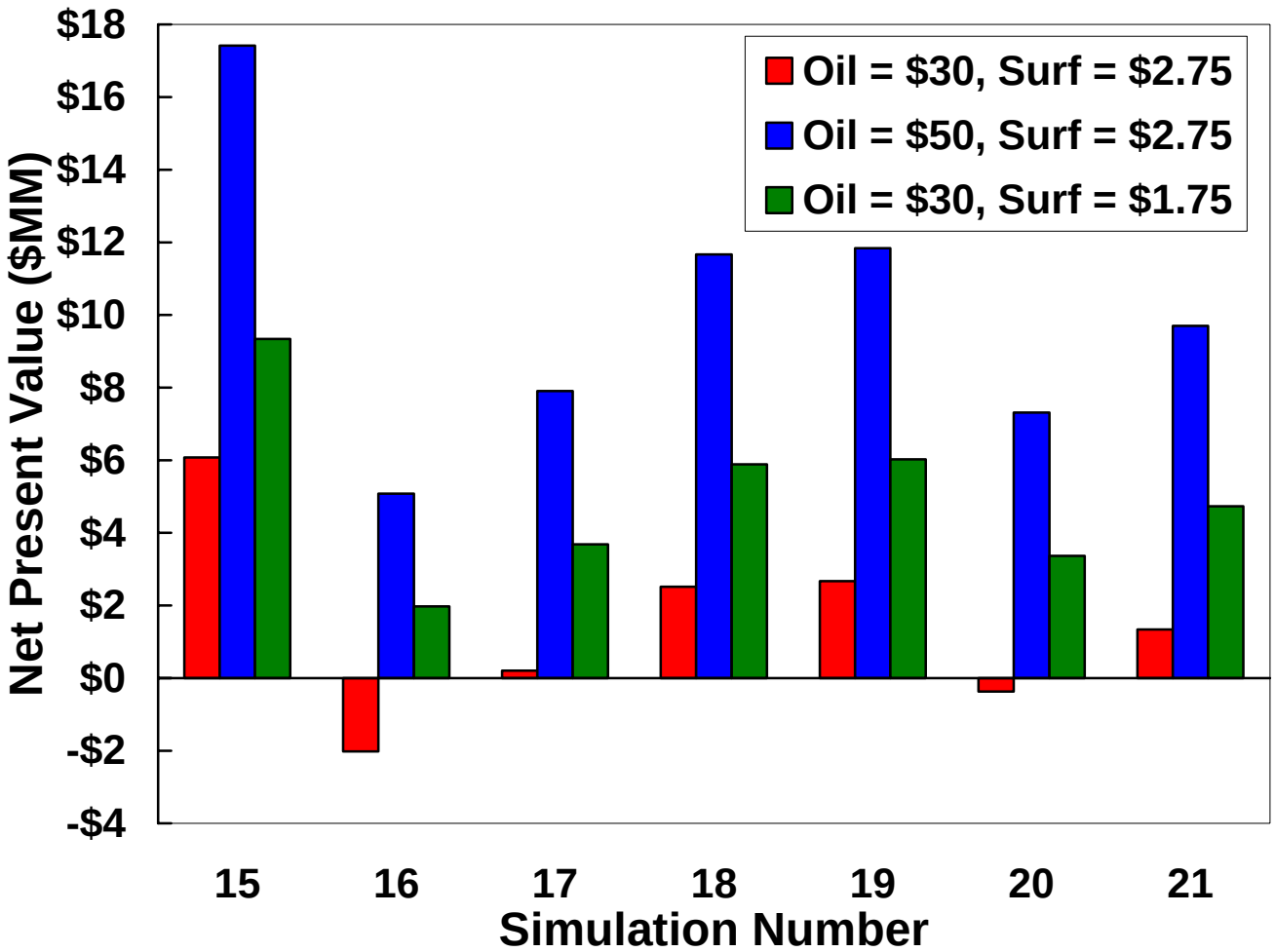
Design Uncertainty Results

Only negative results were from high adsorption (0.6 mg/g) and lower permeability at low oil price and high surfactant cost



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Lessons Learned

- Heterogeneity
  - Channeling causing early fluid breakthrough
  - Increase polymer mass for mobility control
  - Long oil production tail
- Wettability
  - Based on simple fractional flow theory
    - Later oil bank breakthrough
    - Earlier surfactant breakthrough
- Longer project life
  - Well spacing and constraints

Conclusions

- A reservoir model for a Permian basin dolomite reservoir was developed for an S/P optimization study
  - Mixed-wet and heterogeneous
- Base case S/P design was developed using field and laboratory data
  - Unoptimized design had promising recovery and economics
- Sensitivity analysis performed to optimize the S/P design
  - Injecting higher polymer mass will increase recovery and profitability

Conclusions

- At $50 oil and low surfactant adsorption, an S/P flood in one 5-spot pattern could have an NPV of $13 to $17 million with an IRR of ~40%
- Sensitivity and uncertainty analyses show that adverse conditions are still profitable
  - Robust design
- S/P flooding this heterogeneous mixed-wet reservoir is economically feasible
  - Importance of good surfactant performance and careful laboratory evaluation