PTE-574 Optimization Methods for Subsurface Resources Development

Well control optimization of an oilfield operated under waterflood

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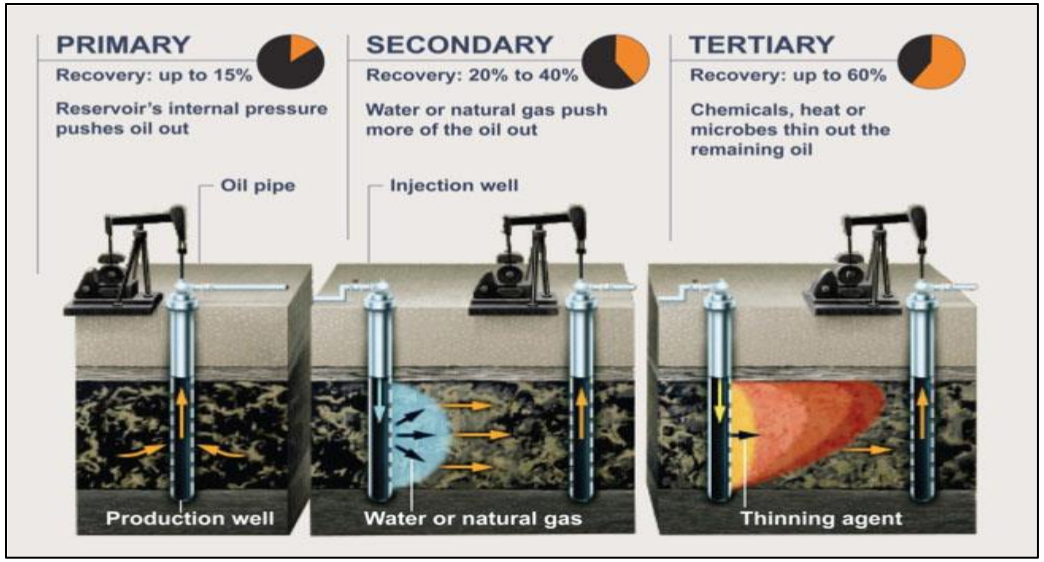
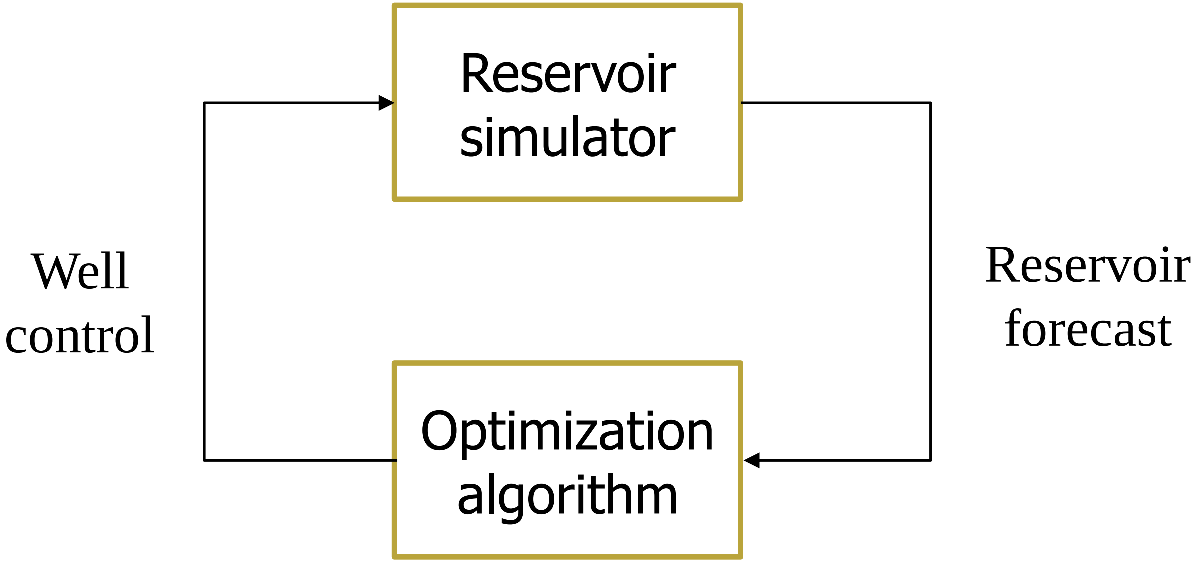
Motivation

- Up to 15% of oil is recovered during primary recovery (source: US DOE)
- The use of secondary recovery methods is thus inevitable (waterflood - the most common approach)
- Still, overall recovery from primary & secondary methods is 10-50%
- More than 50% of oil is left behind
- Among many possible solutions, well control optimization is relatively cheap, widely applicable solution for further optimization of the recovery



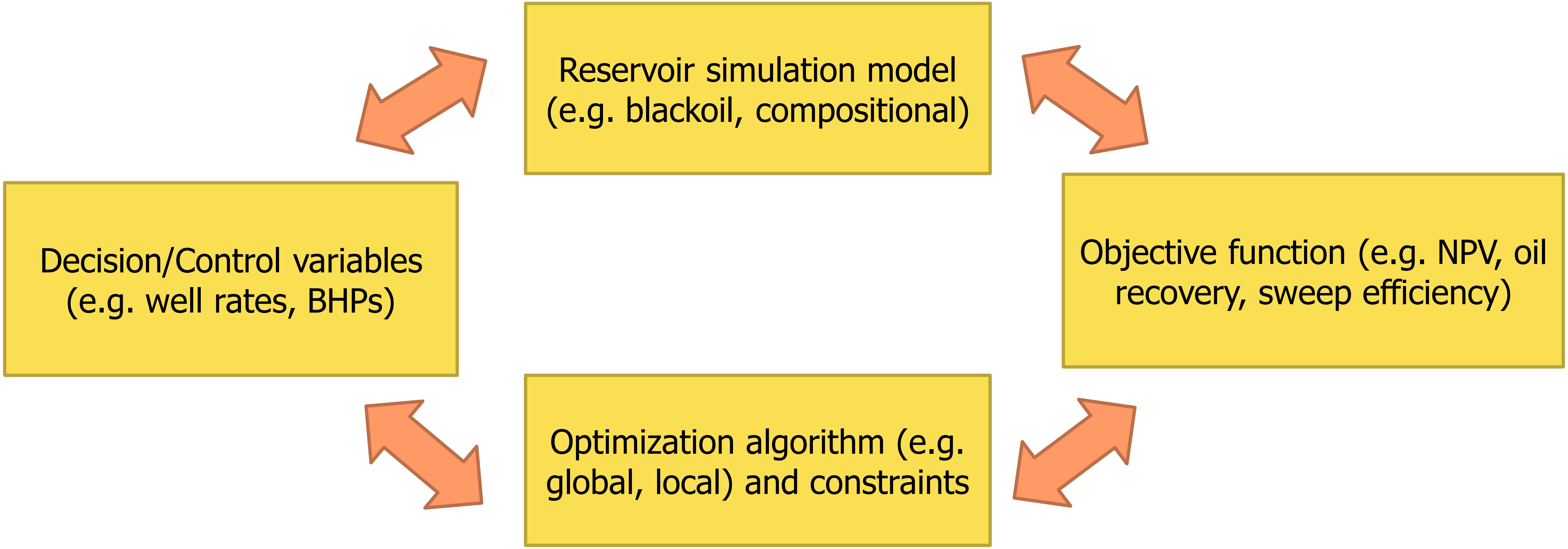
Primary, secondary, tertiary recovery (from petgeo.weebly.com)



Well control optimization loop

Well control optimization

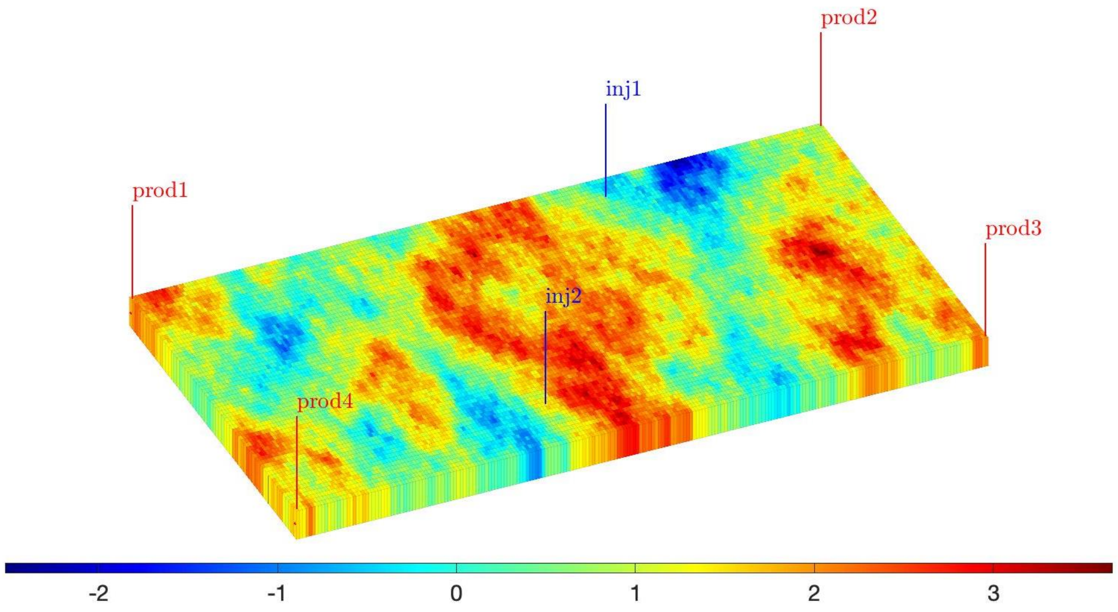
Basic idea: Given a reservoir simulation model for the system, adjust controllable variables of the wells to optimize reservoir performance



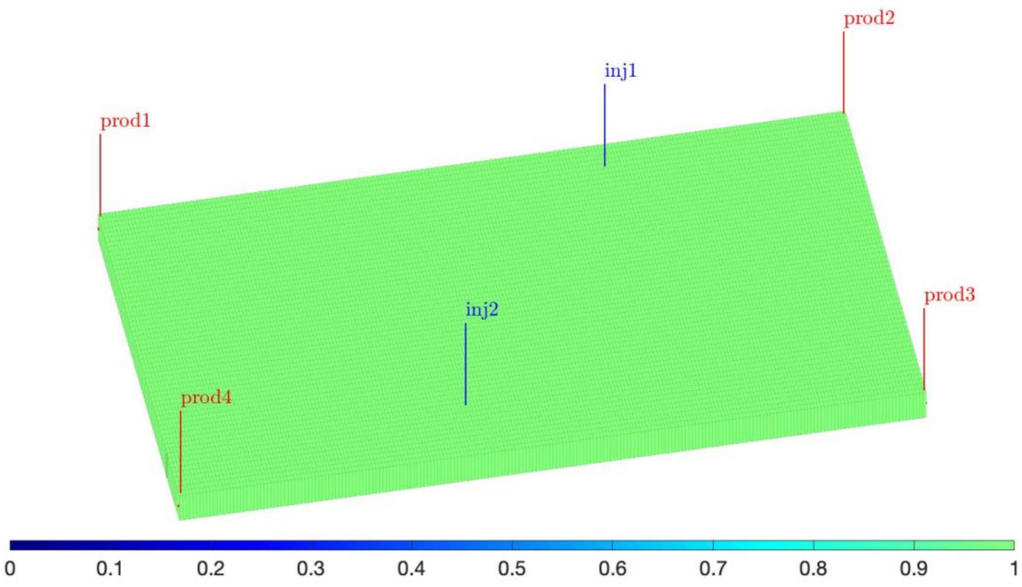
Building blocks for well control optimization

Reservoir model

- **Model shape**: 60x220x1 (layer of SPE 10 model)
- **Fluid phases**: oil and water (incompressible system)
- **Simulated reservoir lifecycle**: 10 years
- **Number of wells**: 4 producers, 2 injectors (all vertical)



Permeability distribution ($k_x = k_y$) (log mD)



Initial oil saturation distribution

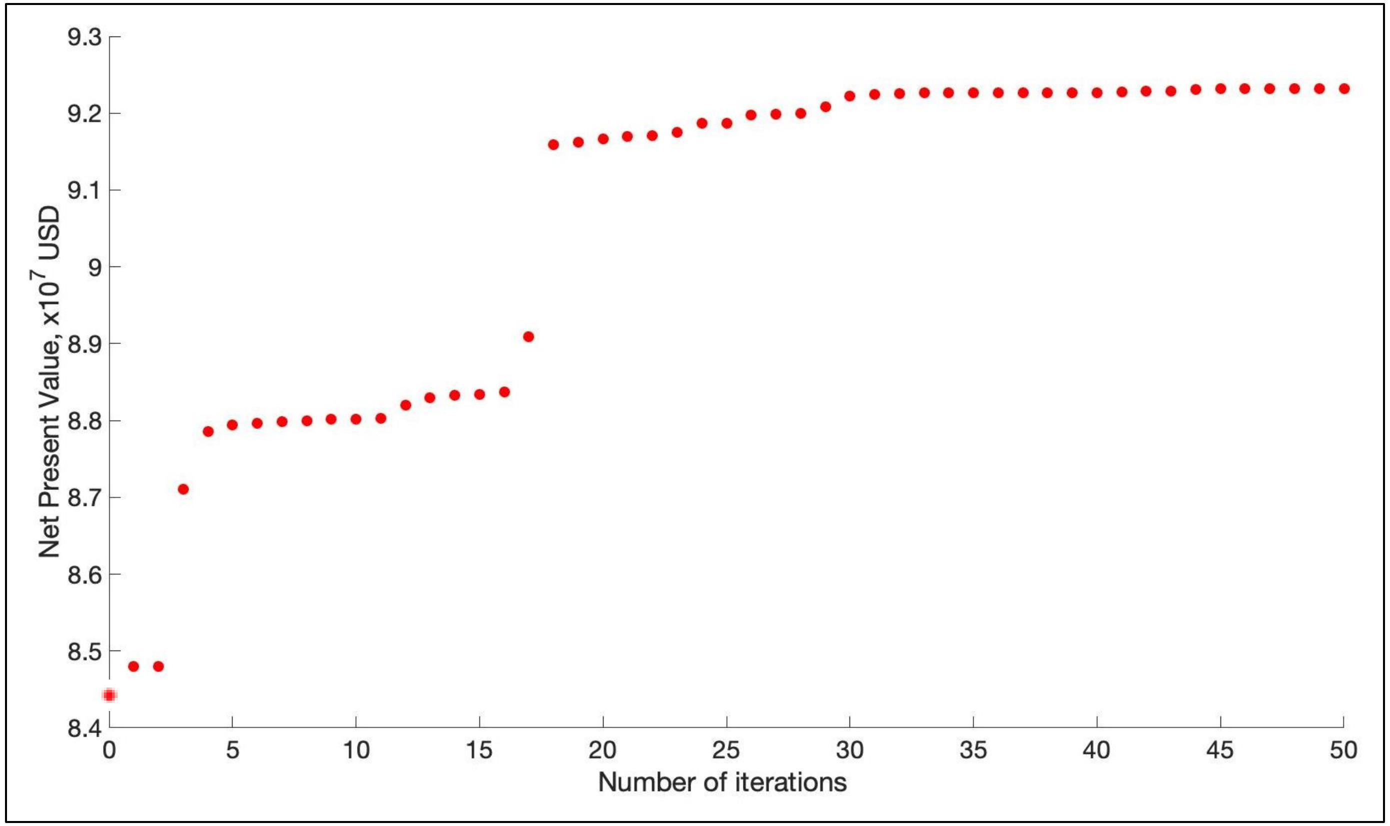
Optimization formulation and details

- **Problem type:** nonlinear constrained optimization with bound constraints
- **Objective function**: NPV
- **Decision variables**:
  - Control frequency: once per year
  - BHP for producers (4x10) : 40 variables
  - Injection rate for injectors (2x10) : 20 variables
  - 60 variables in total
- **Constraints (**bound constraints**):**
  - Injectors – 100-700 stb/day
  - Producers – 500-4500 psia
- **Algorithm:** – interior point (suitable for large, sparse problems (faster than SQP))

  Gradient calculation method: adjoint formulation
- **Stop criteria:** – 50 iterations

Results

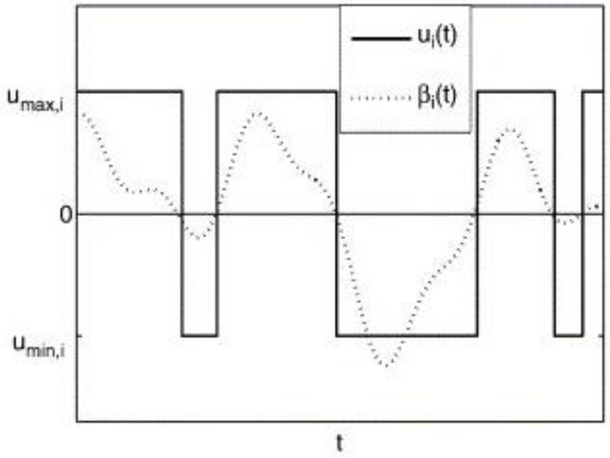
- 7.9 million USD of incremental NPV (9.4% relative increase) was achieved after optimizing well controls



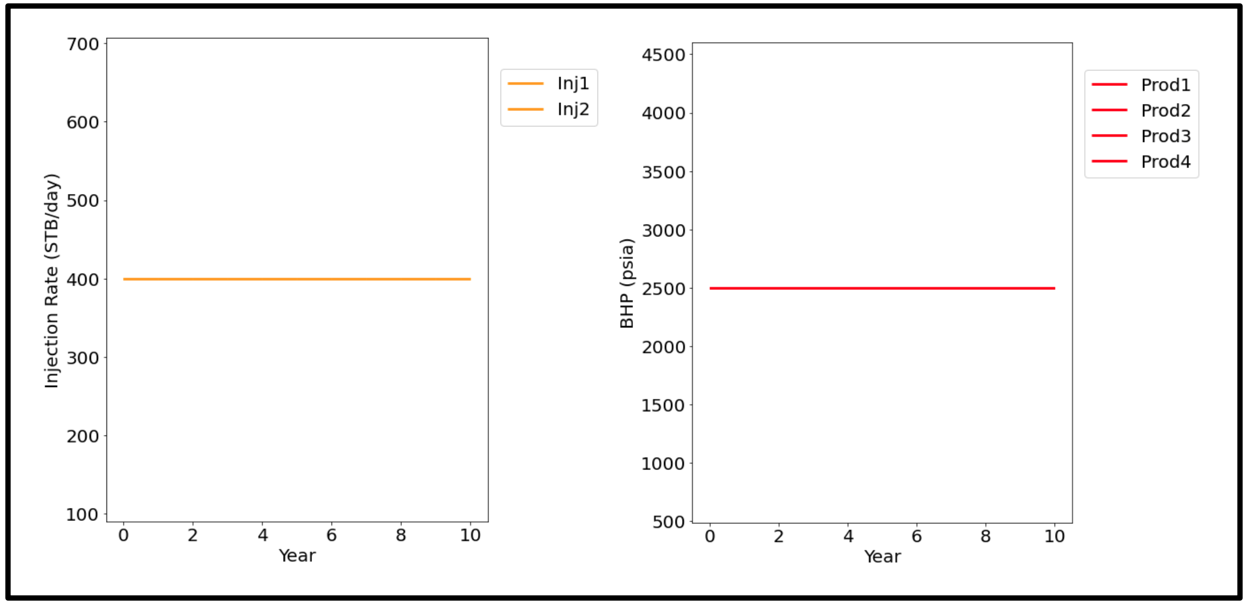
NPV (base case)	NPV (optimized)
8.44×10^7 USD	9.23×10^7 *USD*
7.9 million USD of incremental NPV	
9.4% relative increase in NPV achieved	

Results

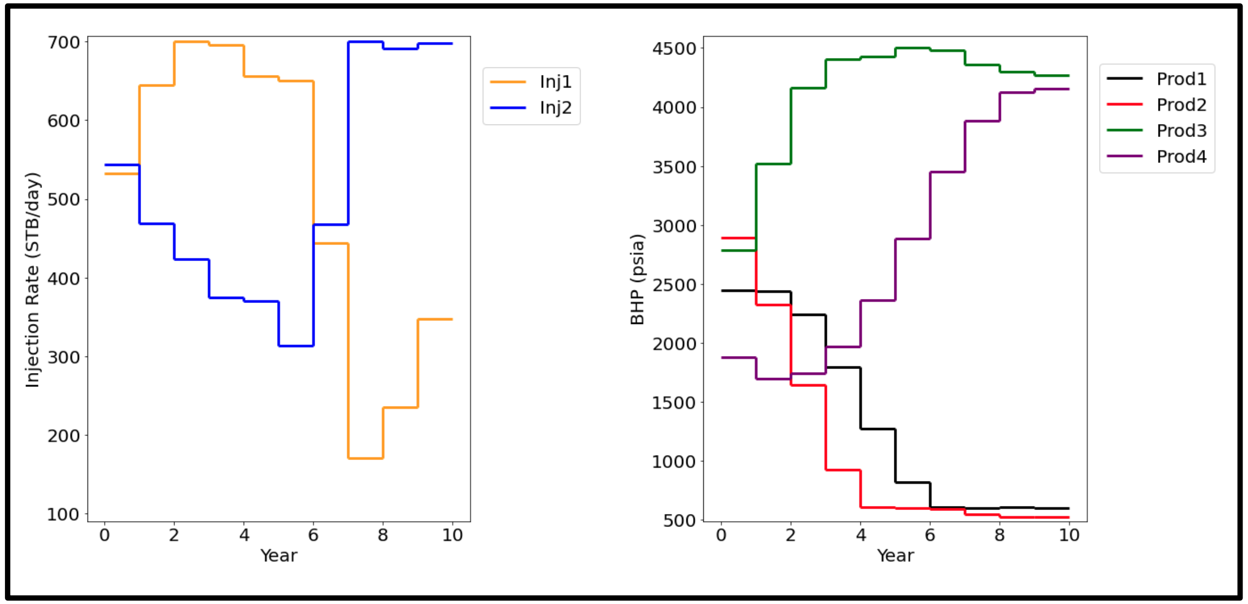
- If only constraints are upper and lower bounds on the control, well control optimization problem will sometimes have bang-bang optimal solutions (Zadvliet et al., 2007)
- No bang-bang control is observed (transitions between controls are mostly gradual)



Bang-bang control u_i (Zadvliet et al., 2007)



Base case control trajectory

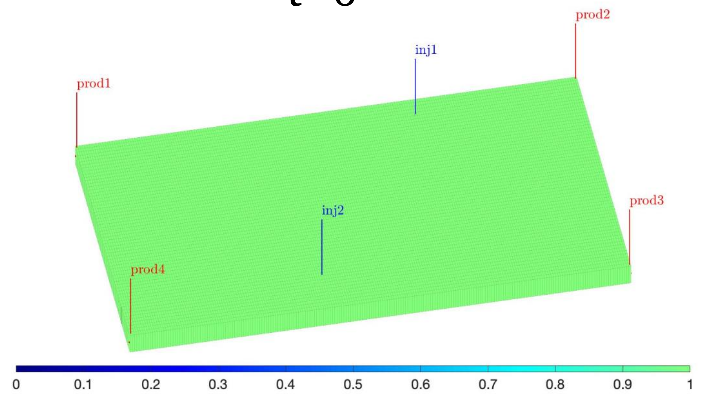


Optimized control trajectory

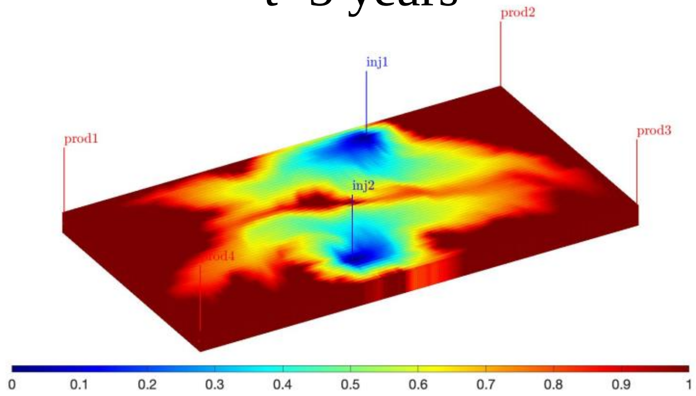
Results

Oil saturation distribution base case

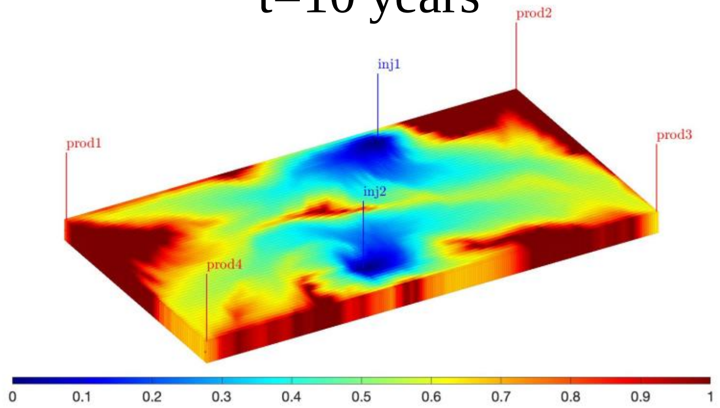
t=0



t=5 years

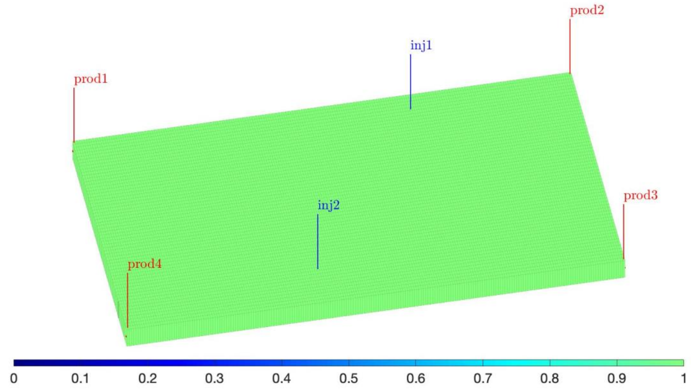


t=10 years

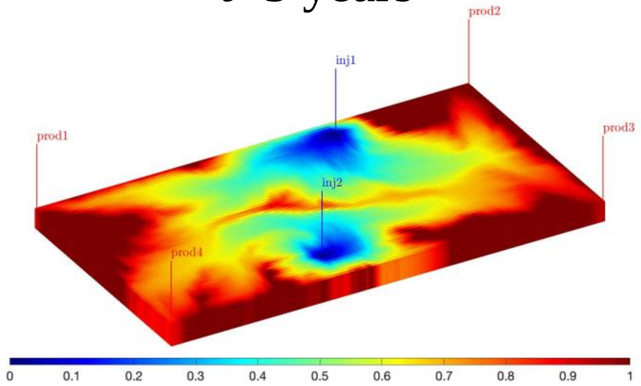


Oil saturation distribution optimized case

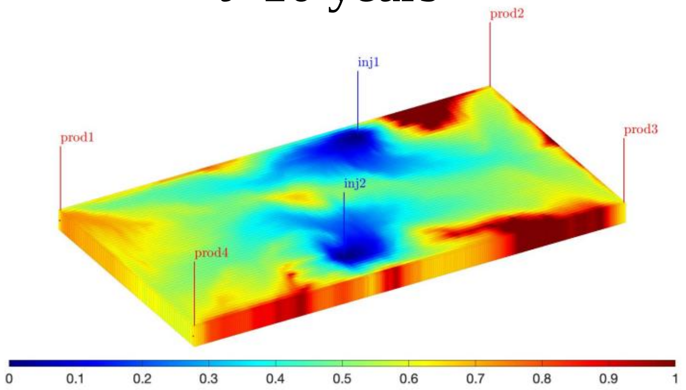
t=0



t=5 years



t=10 years



Conclusion and further work

Conclusion

- Optimized controls lead to 7.9 million USD of incremental NPV (9.4% relative increase)
- No bang-bang control has been observed (transitions between controls are gradual)
- Optimized controls lead to a faster recovery (no significant change in fluid flow paths

Further work

- Different optimization algorithms with a range of parameter settings can be tested
- Variable control steps can be used

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