Optimising CO_2-EOR: oil production and CO_2 storage

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North-America

CO_2 is expensive > minimize use

Other parts of the world

Europe: ETS > use of CO_2 needs to be maximized.
Middle East. Water for use in WAG may be limiting.

Different injection profiles

Main objective: can CO2-EOR projects be optimised for CO2 storage, without compromising oil produced?


Approach

- Use synthetic oil field models
- Immiscible (Eclipse 100) and miscible (Eclipse 300) cases
- Use data from existing fields or published data where possible
- Vertical and horizontal well configuration
- Conventional wells only (no smart wells)
- Define a few reference cases, followed by numerical optimization

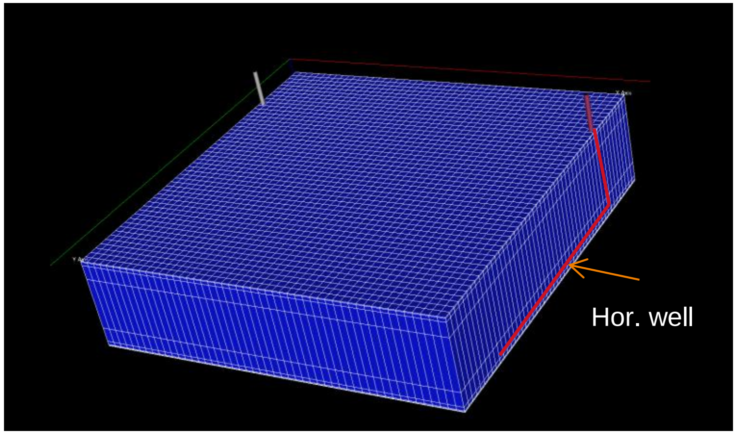
Additional data

- Expected extra oil based on literature:
  - Miscible: 10-15 % of STOIIP
  - Immiscible: 5-7 % of STOIIP

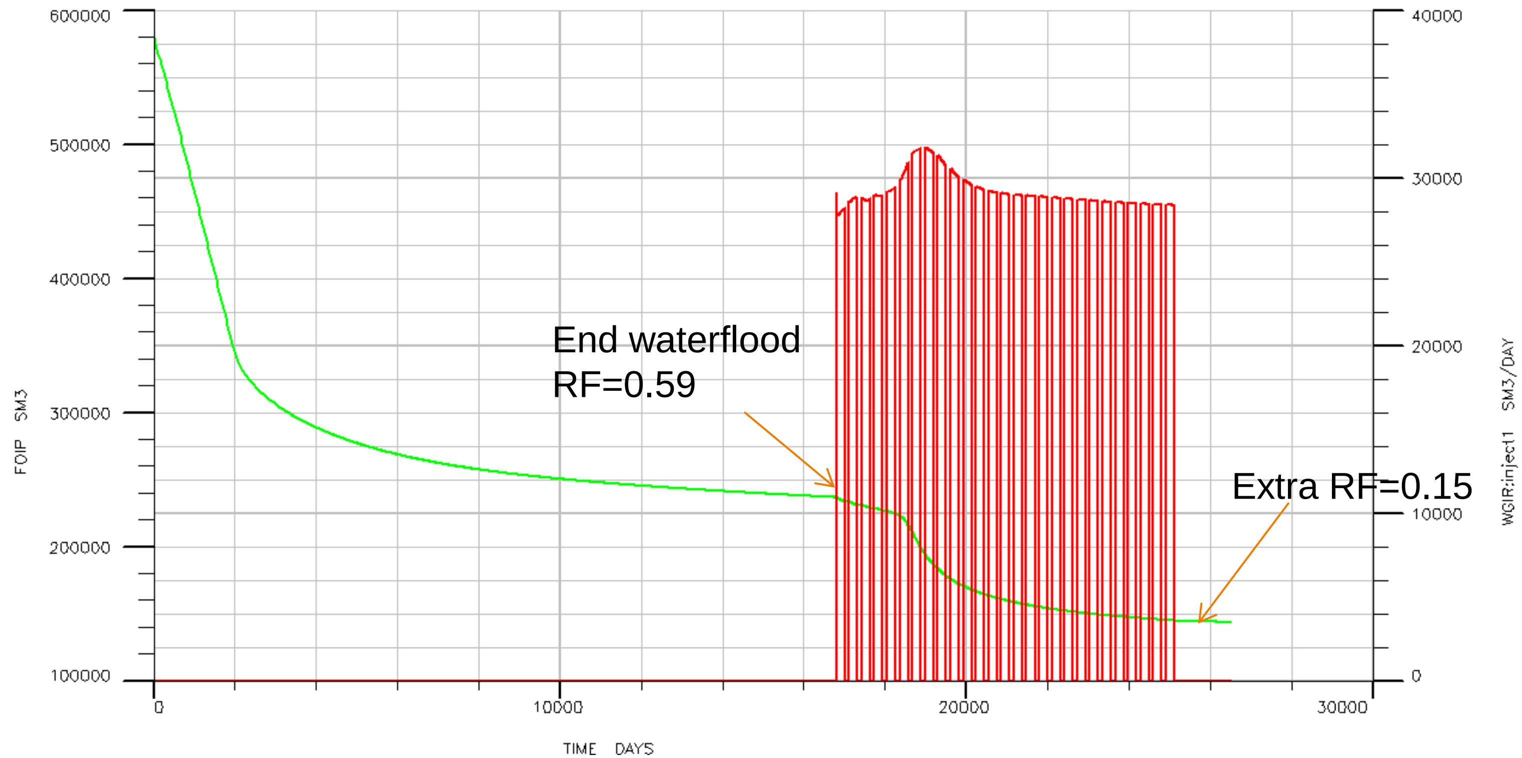
- Reduction perm and increasing time for water flooding
- Using reasonable PVT oil

Miscible base cases (E300)

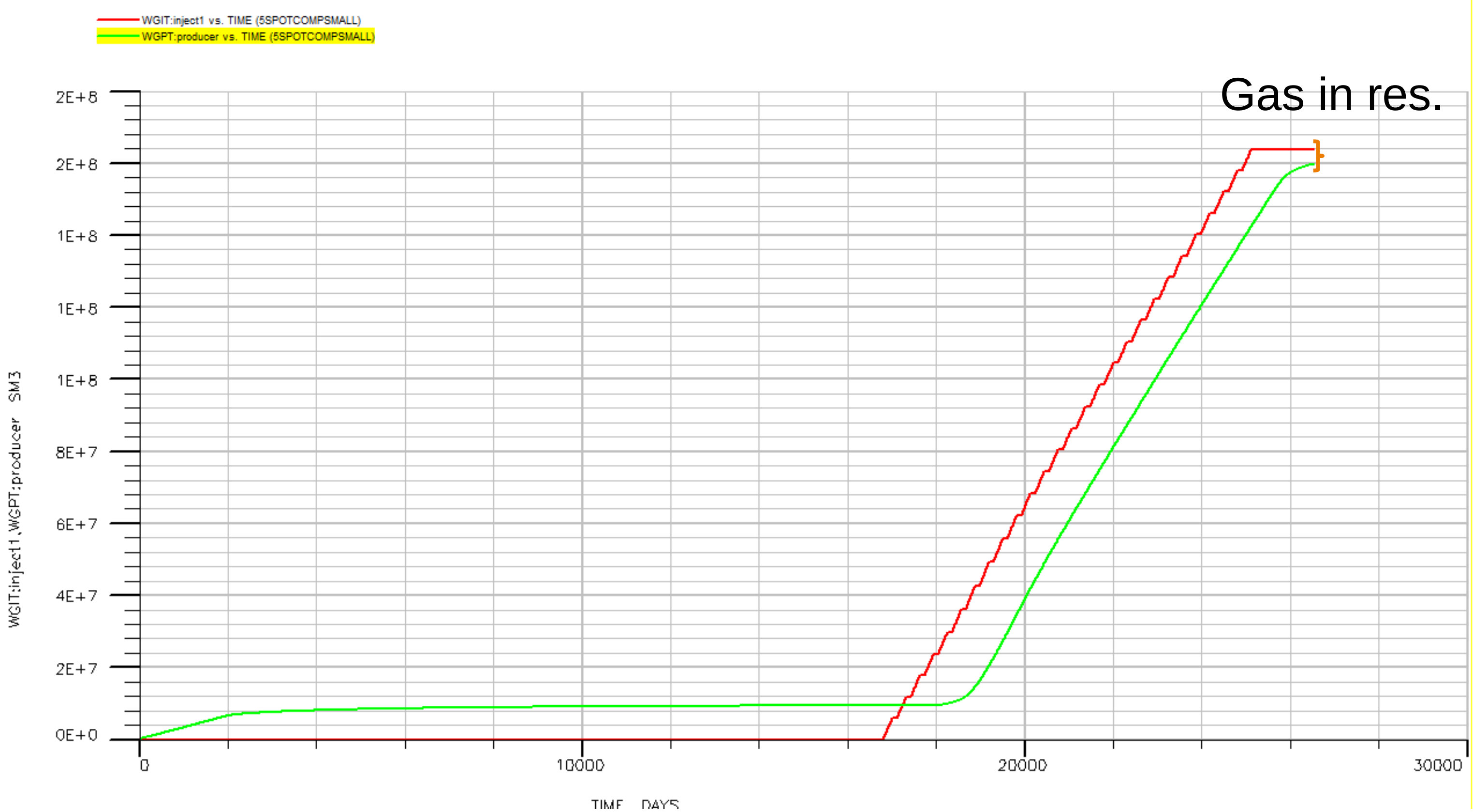
- Compositional data crude (Canadian oil field)
- Relative permeability and capillary pressure curves from SPE 16000 (miscible oil case)
- vertical wells in 40-acre pattern
- 400 m x 400 m (50 x 50 cells)
- 100 m thickness (7 cells)
- K_x = 30 mD, K_z = 30 mD, phi = 0.2
- S_i = 0.28, S_{wc}= 0.2
- Operating limits
  - BHP - 100 bar and 230 bar
  - Water injection - 800 rm^3/d
  - CO2 injection - 800 rm^3/d



Miscible 5-spot
¼ model (faster)



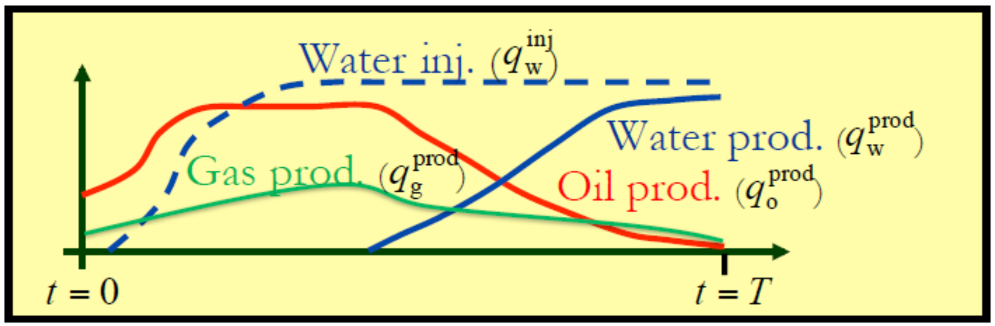
Miscible 5-spot



Net use CO_2 ≈ 0.041 ton/BBL

Ensemble optimization (1) – objective function

- Expressed in terms of produced and injected volumes



- NPV – assign economic cost and revenues to the volumes

$$J = \int_0^T \phi(t)\,\mathrm{d}t, \quad \text{where}$$

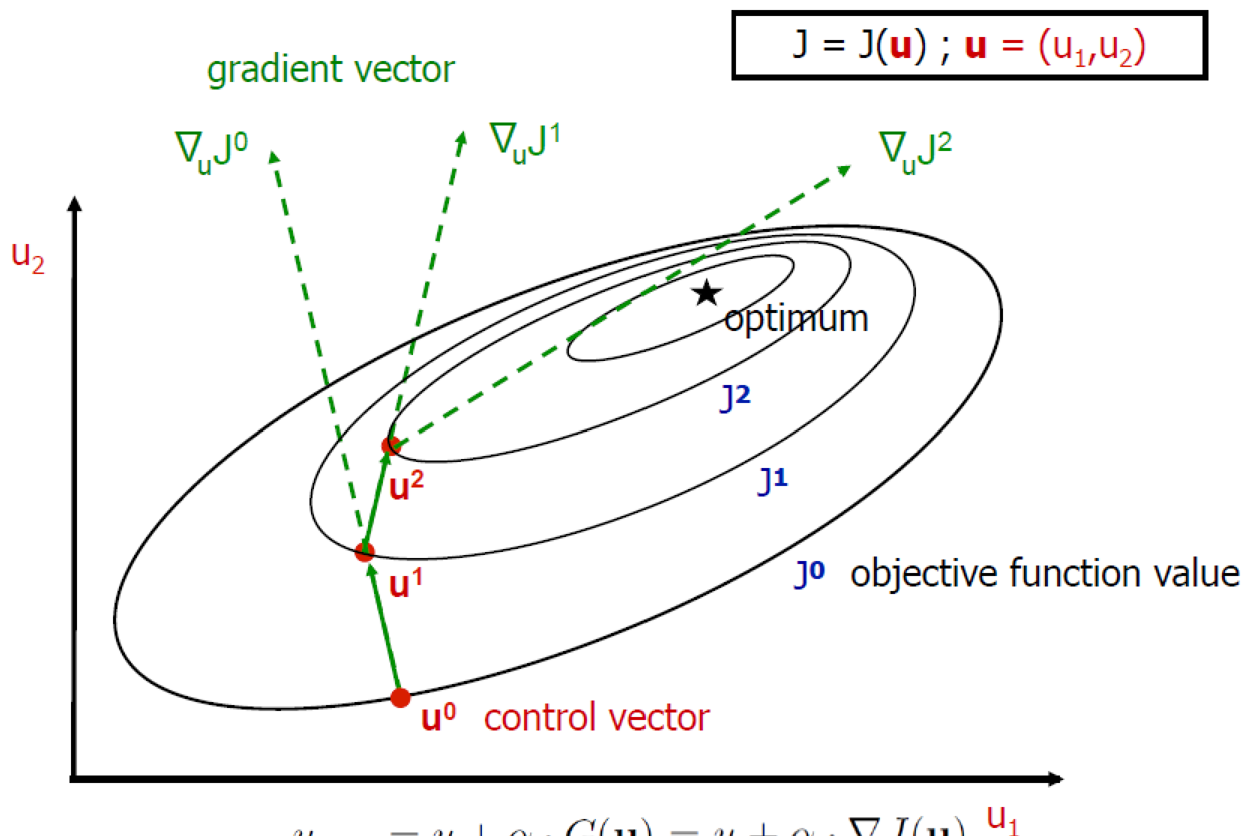
$$\phi(t) = w_{\mathrm{o}}^{\mathrm{prod}}(t) q_{\mathrm{o}}^{\mathrm{prod}}(t) + w_{\mathrm{g}}^{\mathrm{prod}}(t) q_{\mathrm{g}}^{\mathrm{prod}}(t) + w_{\mathrm{w}}^{\mathrm{prod}}(t) q_{\mathrm{w}}^{\mathrm{prod}}(t) + w_{\mathrm{w}}^{\mathrm{inj}}(t) q_{\mathrm{w}}^{\mathrm{inj}}(t)$$

- Discounting – express in terms of value today

$$w_{\mathrm{o}}^{\mathrm{prod}}(t) = w_{\mathrm{o}}^{\mathrm{prod}} \cdot (1 + b)^{-t/\tau}$$

Ensemble optimization (2) – iteration

- Controls are iteratively improved in the direction of the gradient



$$u_{new} = u + \alpha \cdot G(\mathbf{u}) = u + \alpha \cdot \nabla J(\mathbf{u})$$

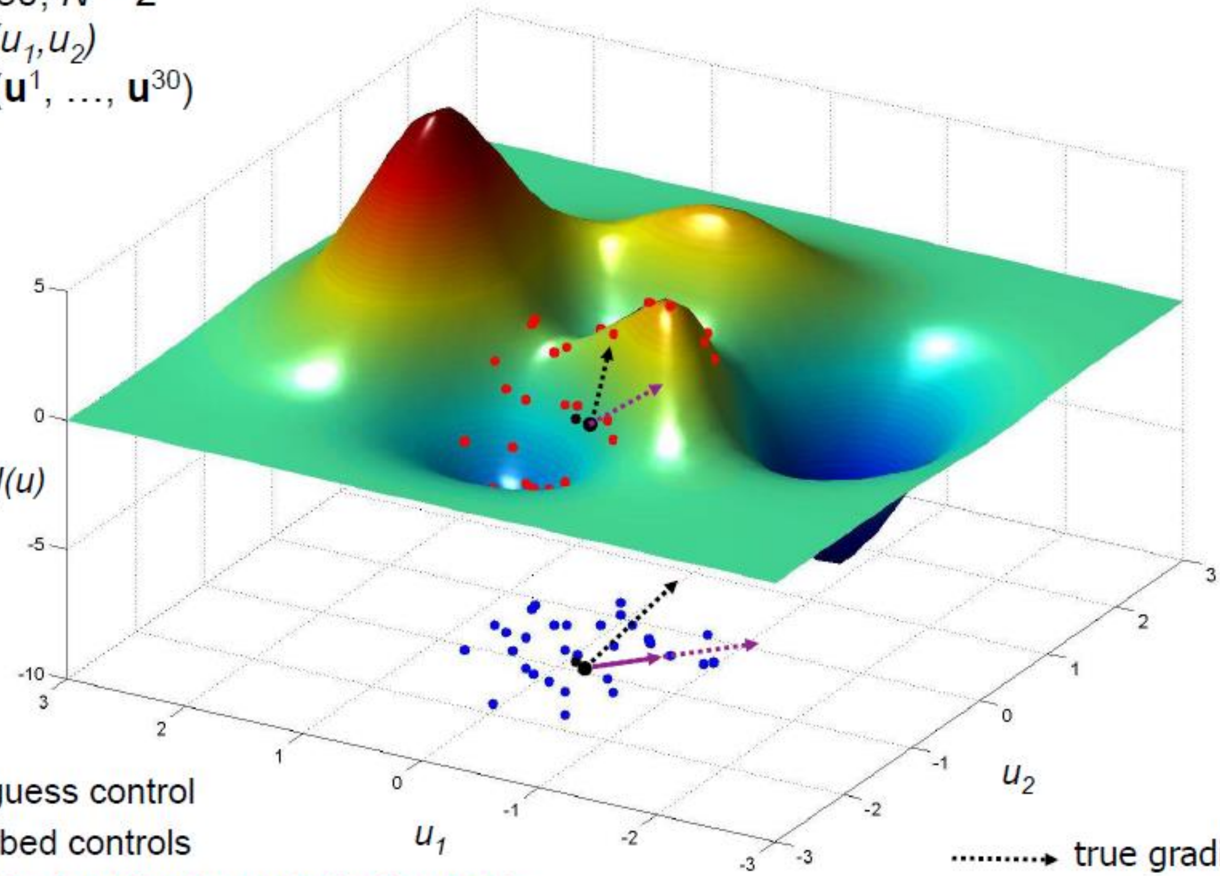

TNO innovation for life

Ensemble optimization (3) – gradient estimation

$M = 30$, $N = 2$

$\mathbf{u} = (u_1, u_2)$

$U = (\mathbf{u}^1, \ldots, \mathbf{u}^{30})$



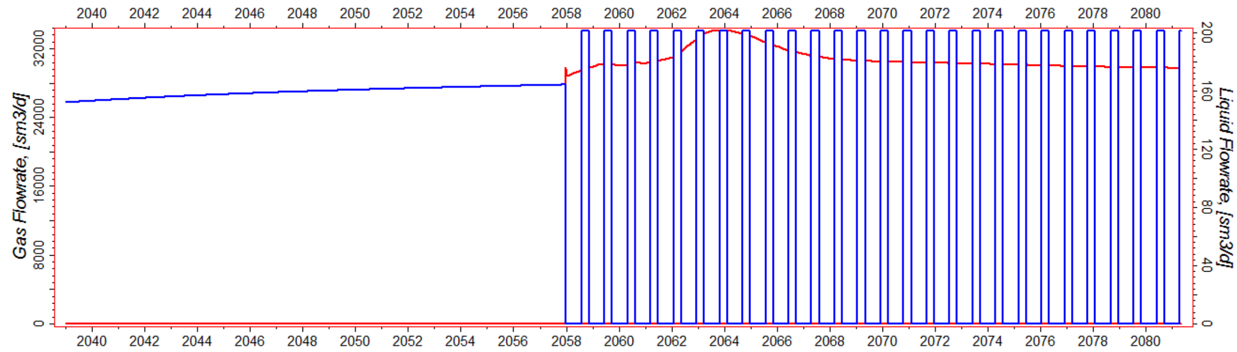
- best guess control
- perturbed controls
- objective function for perturbed controls

true gradient

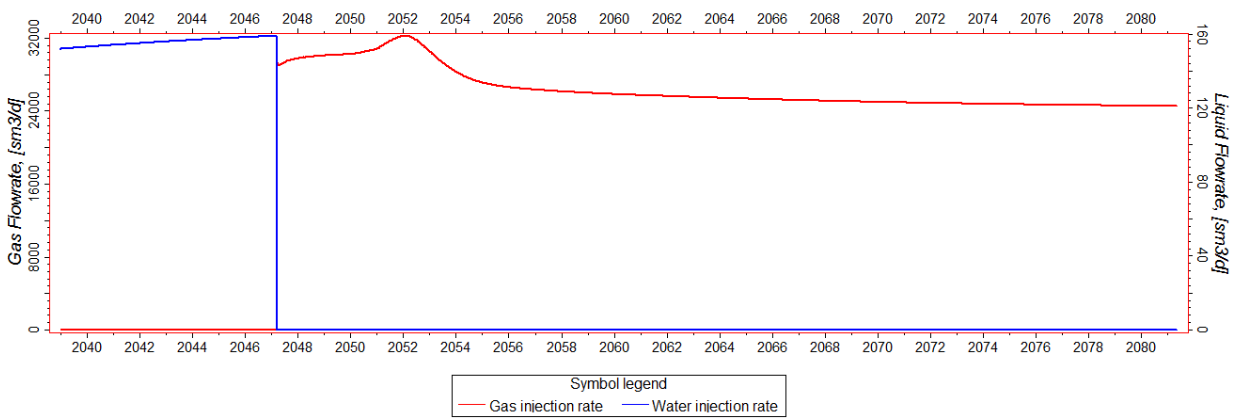
estimated gradient

Miscible optimization case (5-spot, E300)

- **Initial**. Stored CO_2 = 36.4·10^6 m^3 ; Oil recovered = 425345 m^3



- **Final**. Stored CO_2 = 50.7·10^6 m^3 (+39%) ; Oil recovered = 424911 m^3 (-0.1%)



Conclusions

Economic aspects affect the way the EOR should be conducted. These aspects may differ from region to region. This is true for miscible and immiscible CO_2 EOR

The same amount of oil recovery can be reached with different CO_2-water injection schemes.

The best one of these (in terms of economics) can be found using numerical optimization methods applied to combined economic and reservoir models. TNO developed an ensemble-based optimization approach to demonstrate this.

Further/current steps

- Perform optimization for other well geometry-oil property combinations and economic models appropriate for different regions
- Implement tax regimes in economic model (next year)
- Application on an actual oil reservoir in which CO_2 EOR is applied (now).