Sensitivity of Hydrocarbon Recovery by CO_2 Injection to Production Constraints and Fluid Behavior

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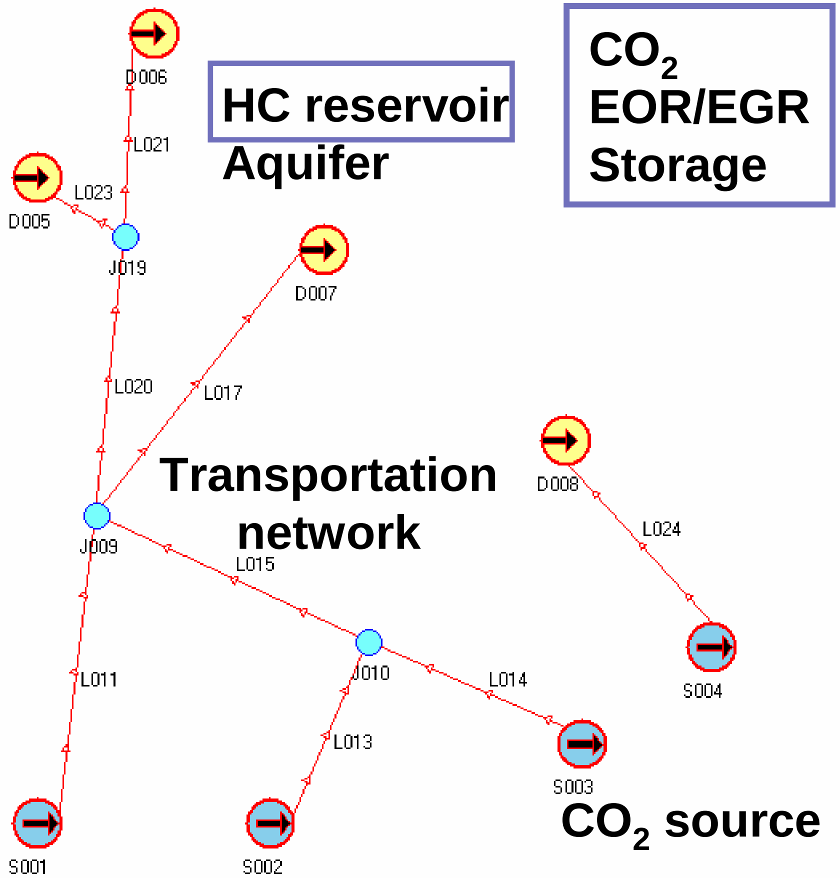
Outline

- Introduction
- Reservoir Conceptual Modeling for techno-economic evaluation
- Illustration 1: CO_2 EOR, Ivanić field, Croatia
- Illustration 2: CO_2 EGR, 'Ursa' field, Hungary
- Conclusions

Introduction

- ECCO:
  CO_2 value chain

  Technical Constraints
  - CO_2 source: CO_2 emission rate
  - Network / CO_2 Pressure & Temp.
  - Reservoir : actual pressure, injectivity



- a large-scale problem, complex to solve

  → reservoir/field **conceptual modeling** needed for each CO_2 EOR/EGR/storage target

Introduction

- Reservoir Conceptual Modeling
  - One hydrocarbon field = multiple injectors represented explicitly

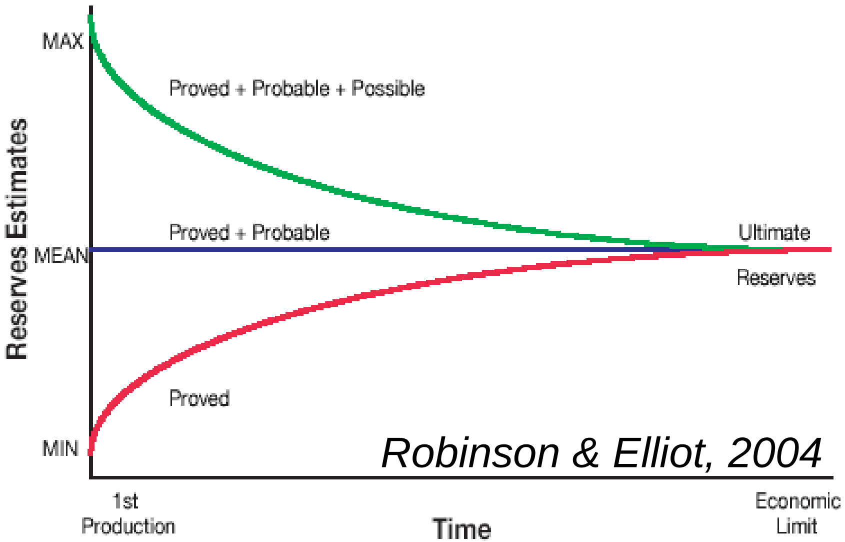
    → reservoir/field **conceptual modeling** needed at a sector scale, well scheduling needed

  - or one hydrocarbon field = one single « injection » point in the full CO_2 injection network

    → reservoir/field **conceptual modeling** needed at the field scale

Introduction

- ECCO: North Sea & **Central Europe**
  - Context in Central Europe
    Targets = pre selected mature hydrocarbon fields



→ reduced
geological uncertainty

→ what remains unknown:
the impact of
production constraints

Methodology for reservoir conceptual modeling

- Get full field CO_2 injection “experience” on pre selected fields
  actual / **virtual (through full field simulation)**

- Run a sensitivity study to production constraints
  using experimental design tool

- Simulation results: input data for dimensionless performance curves

Scoping model

Input = scaling variables (IOIP, ..)

↓

Core = Dimensionless Performance Curves

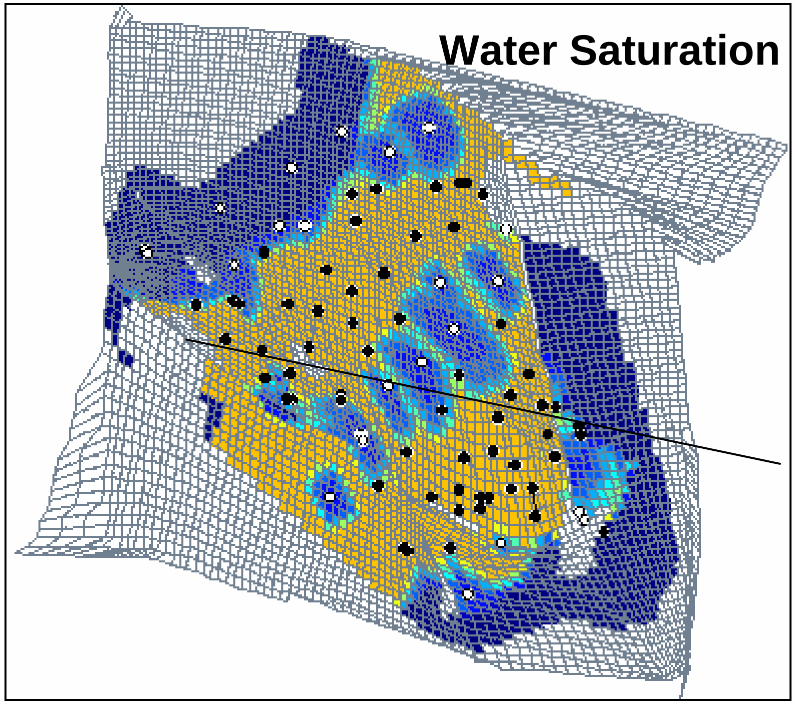
↓

Output = Scaled Performance

Illustration 1: Ivanić CO_2 EOR case

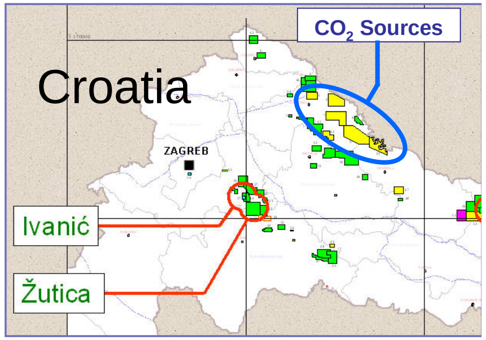
Depth: 1609 m T: **98°C** P: **184 bar**

Reservoir oil: Pb: 138 bar, 33.4 API

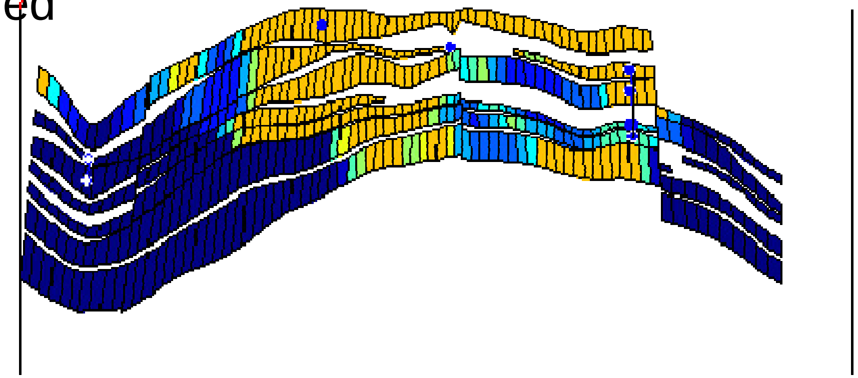


Simulation of production history (depletion + water flooding)

High well density
➔ wells interferences



Geology:
Presence of faults, pinch-out, stratified



History has been matched

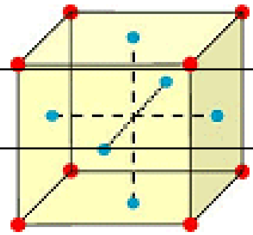
Test on fluid behavior (EOS): no CO_2 initially in reservoir oil

Sensitivity analysis with experimental design COUGAR™

"Uncertain" parameters in dynamic reservoir model:

- BHPlim $\in$ [Min,Max],
- GORlim $\in$ Min,Max],

Experimental design

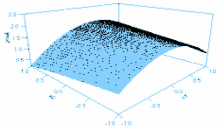


N simulations

Launch reservoir simulations
Define the response(s): Prod

BHPlim	GORlim	Prod
1	1	0.58
-1	1	0.36
1	-1	0.70
-1	-1	0.51
0	0	0.96
1	0	0.24
-1	0	0.29

Compute Response Surface
Model: Prod = f(BHPlim, Qmax)



RSM
(Least square regression)

$$\mathit{Prod} = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_{12}x_1x_2 + a_{13}x_1x_3 + a_{23}x_2x_3 + a_{11}x_1^2 + a_{22}x_2^2 + a_{33}x_3^2$$

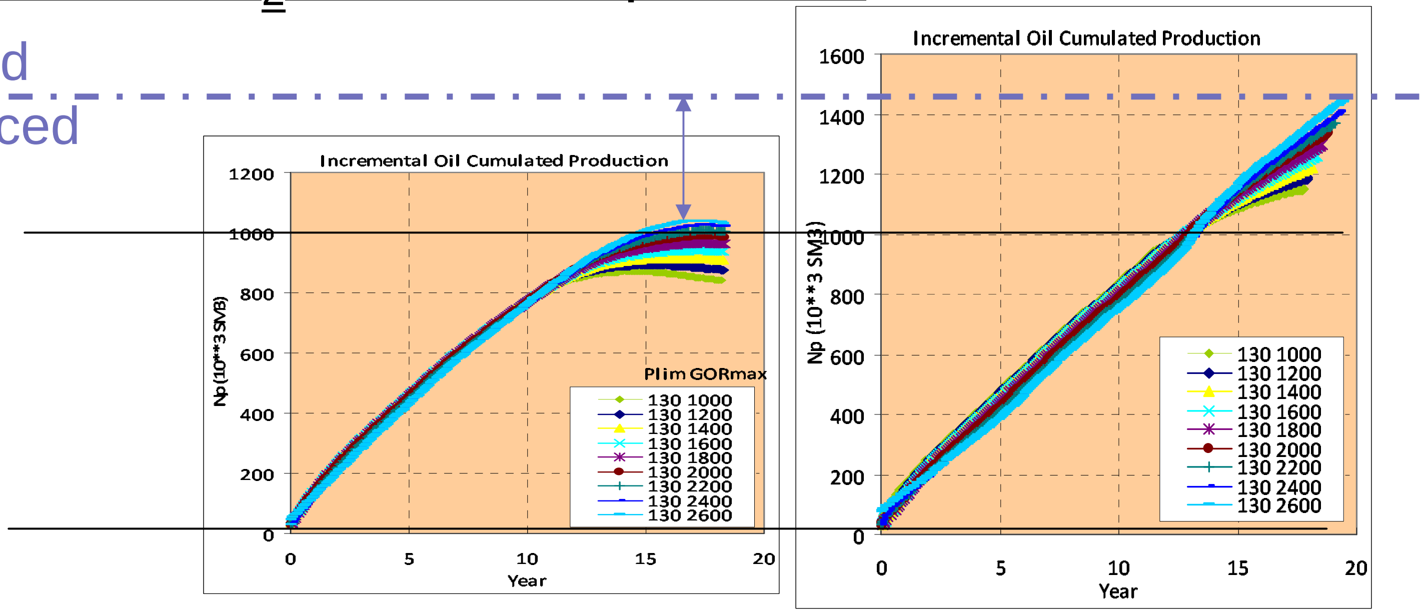
Use of 2 fluid models (EOS): low/high CO_2 dissolution (through CO_2 / Heavy binary interaction coefficients), history still matched

Illustration 1: CO_2 EOR in IVANIĆ field

(injection pressure (BHP): 150 bar)

Impact of the CO_2 dissolution potential

Cumulated Oil Produced



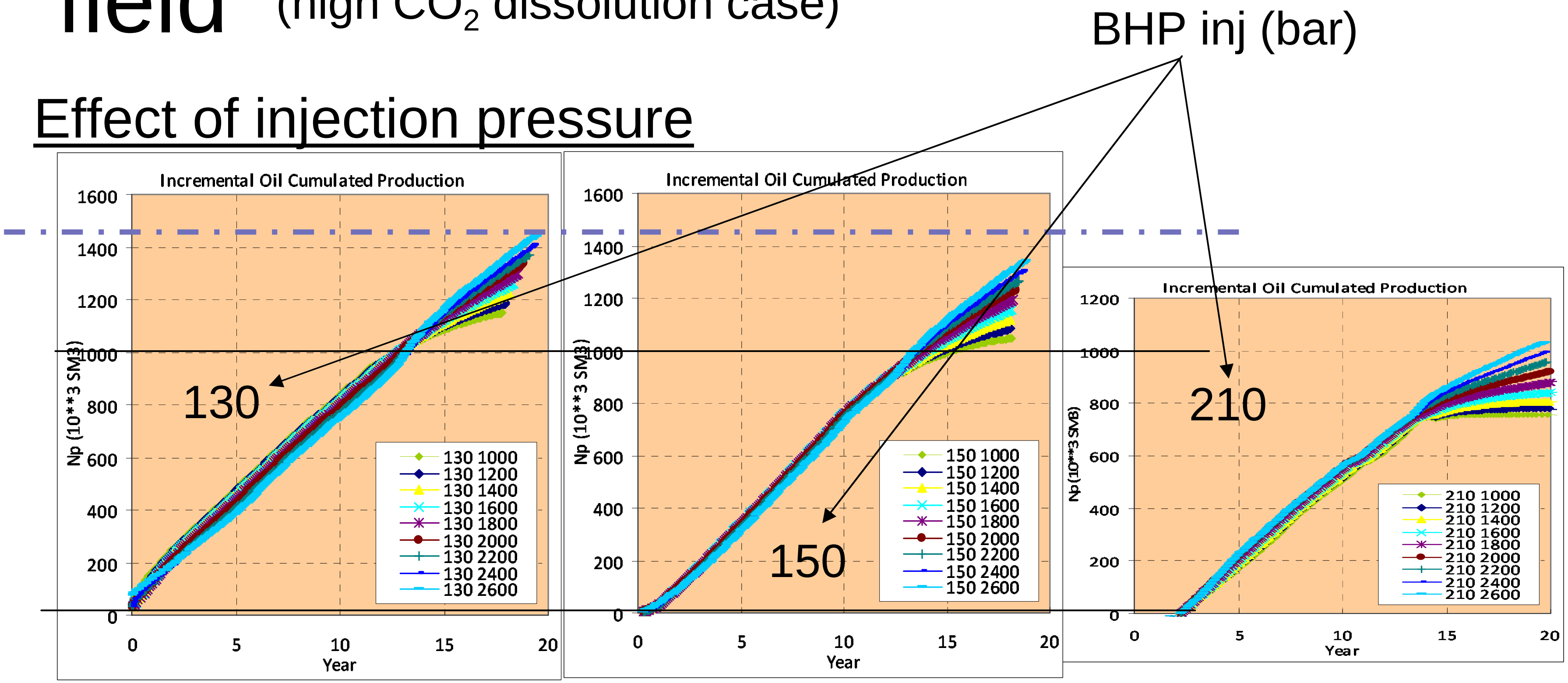
CO_2 dissolution **low** **high**

Observed: larger the CO_2 dissolution, higher the oil recovery

As expected, more miscibility, more oil recovery

Illustration 1: CO_2 EOR in IVANIĆ field (high CO_2 dissolution case)

Effect of injection pressure



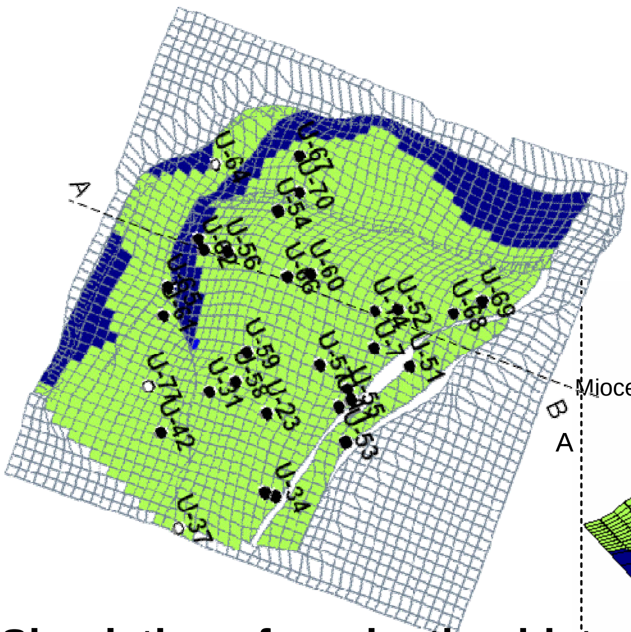
Observed: higher the pressure, lower the recovery

Explanation: BHP producer related to BHP injector,
time is needed for reservoir repressurisation, recovery is delayed

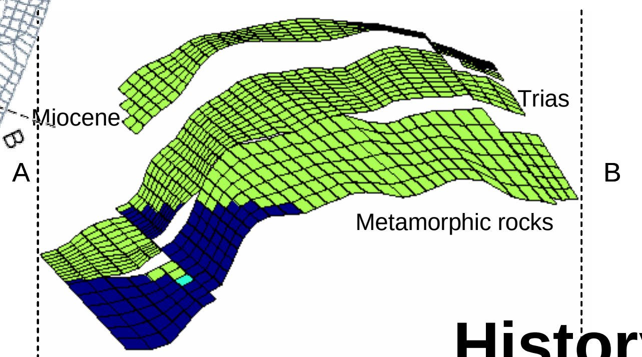
Illustration 2: URSA CO_2 EGR case

Depth: 2800-3150 m GG: 0.81 T: **144°C** P: **330 bar** P_{dp}: **276 bar**

Very mature field, Hungary



Geology :
3 main units
stratified, heterogeneous
bad vertical communication



Simulation of production history
(depletion, gas & condensate production)

History has been matched

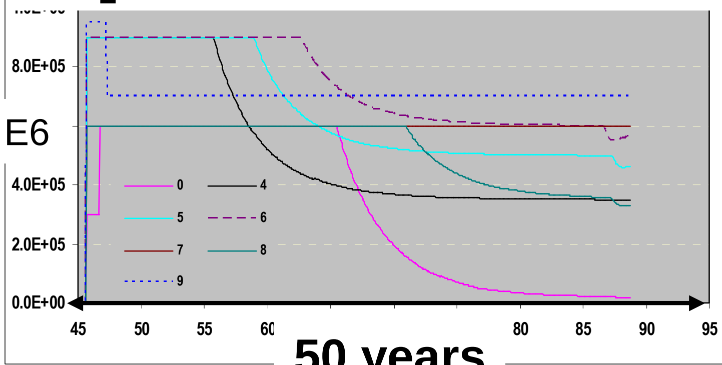
Illustration 2: URSA CO_2 EGR injection scenarios

- Injectors: downdip, gravity stabilizing
  favorable mobility ratio (CO_2 more viscous)
  gas phase “ fully” miscible displacement

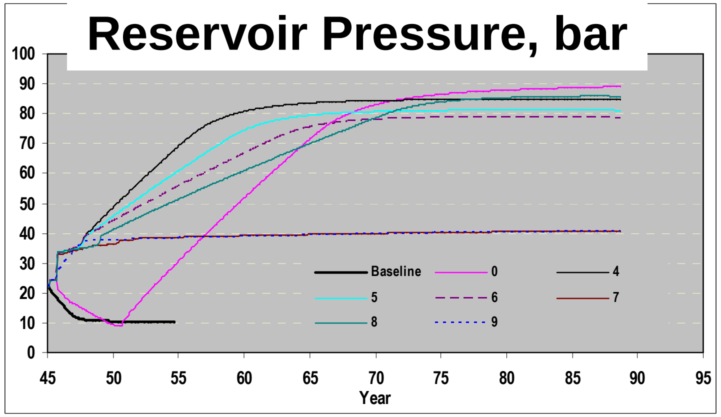
- Scenarios
  - Inject CO_2 while reservoir blow-down then store CO_2 with reservoir re-pressurization
  - Inject CO_2 while re-pressurize
  - Various injection rates

Illustration 2: Ursa CO_2 EGR

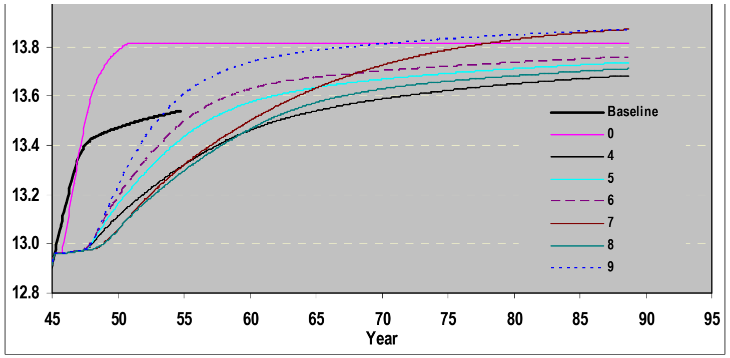
CO_2 injection rate ,10^9 Sm3/D



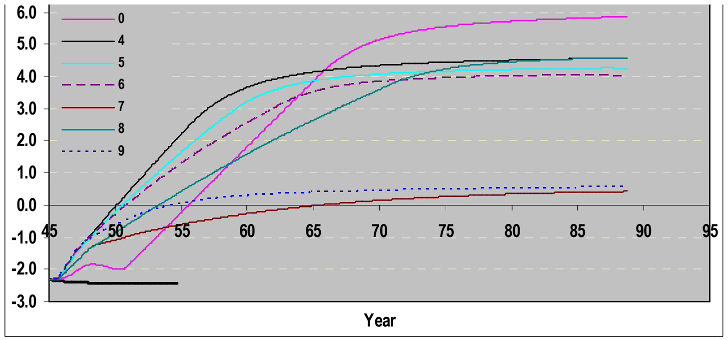
Reservoir Pressure, bar



Net gas cumulated prod. ,10^9 Sm3



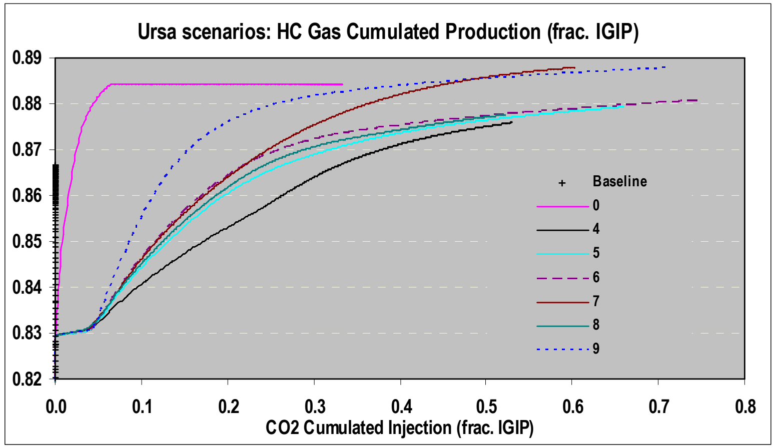
Cumulated stored CO_2 ,10^6 tons

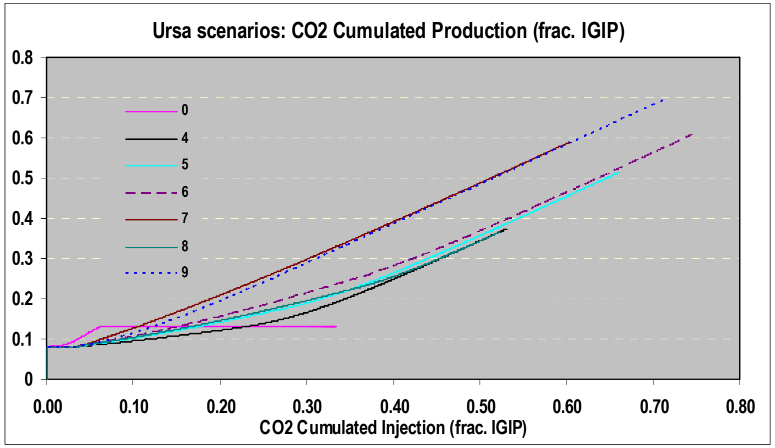


- Final recovery sensitive to production constraints, and very different production profiles. Maximum EGR for scenario “inject then store” (pink line)

Illustration 2: Ursa CO_2 EGR

- Dimensionless Curves



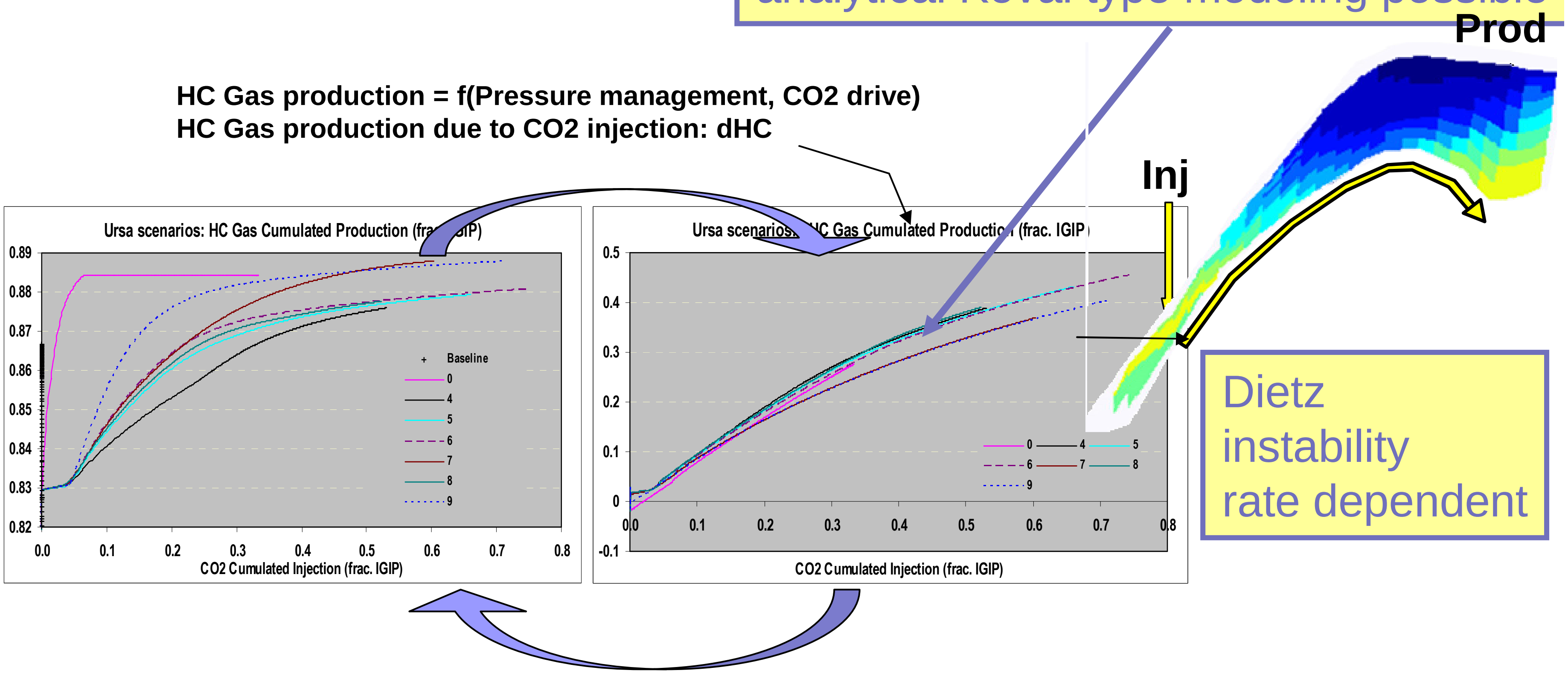


A dimensionless approach
which does not take into account the pressure management
(depletion, recompression before/during CO2 injection)
does not allow for putting all the results on a single set of dimensionless curves

Illustration 2: Ursa CO_2 EGR

- Dimensionless Curves

Signature of unstable displacement, analytical Koval type modeling possible



Dietz instability rate dependent

Redimensioning dimensionless curves needs to have a scenario for pressure management

Conclusions

- Production constraints are found to have a large impact on hydrocarbon recovery by CO_2 injection
- Effects of thermodynamics
  - As expected, higher the solubility of CO_2 in the reservoir oil, higher the recovery.
  - CO_2 solubility, if not measured, is a source of uncertainty on EOR, quantifiable through a sensitivity to EOS binary interaction parameters
- For a given reservoir fluid and given geological parameters, increasing the pressure for increasing the miscibility is found to have a negative impact on oil recovery ; the re-pressurization induces a delay in oil recovery:
  - Starting the CO_2 injection at the actual reservoir pressure of a depleted oil reservoir, the positive effect of the re-pressurization (increased miscibility) on the recovery has not been met during the 20 years of CO_2 injection.

Conclusions

- CO_2 EGR, even in the most favorable injection conditions for getting a stabilized front, is found to be highly sensitive to heterogeneity, injection rate and pressure management
  - Evidence of "Dietz like" instability,
- "Dietz like" instability modeling: analytical Koval type model appears usable once the pressure effects deconvolved
- Reservoir conceptual modeling for techno-economic large scale project evaluation: reservoir conceptual modeling missing the impact of production constraints (pressure and rate) on the hydrocarbon recovery appears not to be usable for the gas or live oil reservoirs which have been studied

- Thank you for your attention

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