IRIS

CO_2 utilisation

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Overview

IRIS

- Differences with storage
- Physics: miscibility, dispersion, temperature
- Enhanced Oil Recovery
- Enhanced Gas Recovery
- Concluding remarks

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Yet technical questions need to be looked upon and me might need to look at big picture!

CO_2 requirement for EOR is not constant with time: CO_2 will breakthrough and need to be recycled

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What are those physical phenomena?

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Transport phenomena

- Viscous forces
- Diffusive forces
- Gravity forces
- Capillary forces
- Mobility control

CO_2 specific aspects

- Three non-aqueous phases
- Chemical interaction with reservoir rock
- Supercritical behaviour

Compositional aspects

- Swelling of oil
- Condensing / vaporising gas drive
- Miscibility development - IFT effects
- Miscibility in water

Rock properties

- Reservoir compaction/dilation
- Sealing faults
- Cap rock integrity

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What those phenomena mean for EOR?

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Compositional aspects:

- CO_2 may evaporate hydrocarbons into mobile CO_2-rich phase;
- Oil viscosity reduces with dissolution of CO_2 ;
- Oil formation volume factor increases by 40-70% due to oil swelling with dissolution of CO_2;
- Interfacial tension on the oil-water contact reduces in the presence of CO_2 in both phases.

Miscibility in water:

- CO_2 is soluble in water - much higher solubility than for methane or nitrogen (additional safe storage);
- CO_2 dissolution in water increase aqueous viscosity and density.

Chemical interactions:

- Chemical reactions with CO_2 may increase permeability in sandstones by 5-15%, in carbonates and dolomites by 6-75%.

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!!! CO_2 injection significantly increase precipitation of heavy hydrocarbons like asphaltines - this must be investigated.

Evaluation of CO_2 injection

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To evaluate applicability of the CO_2 to particular field an analytical package like SWORD could be used

Analytical model accounts only for miscibility development

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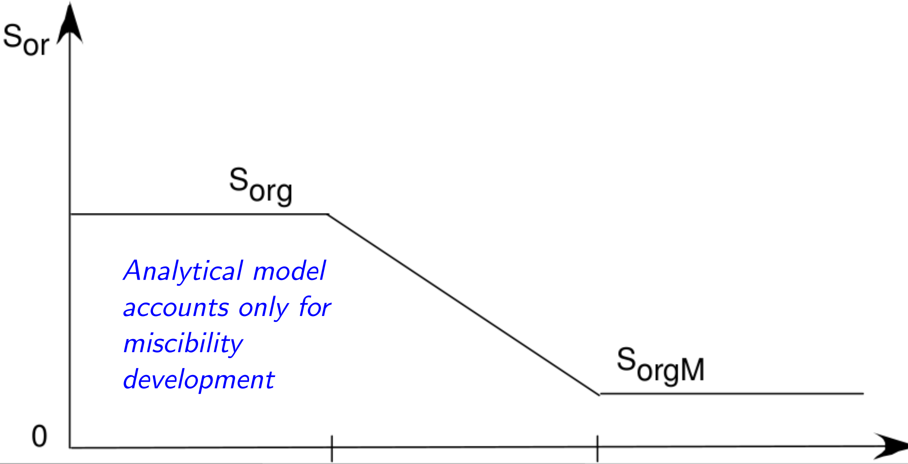

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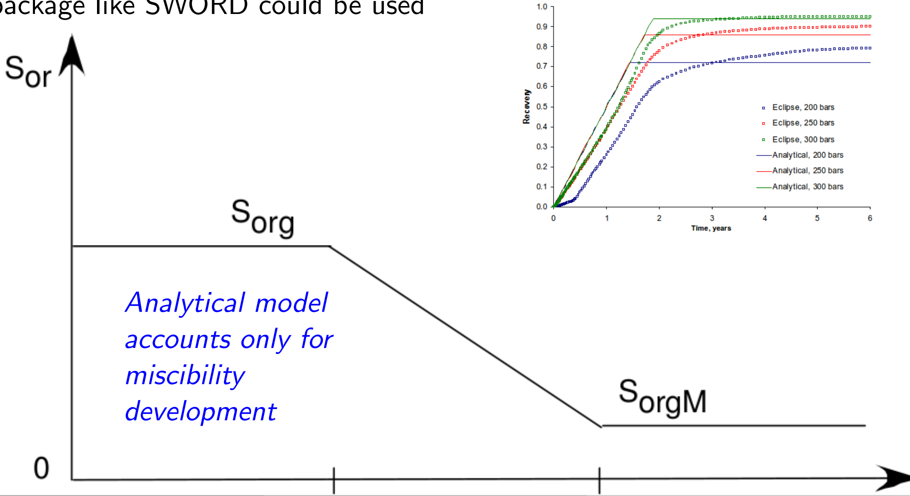


Analytical model accounts only for miscibility development

EOR: analytic screening. Expert system

IRIS

Sword

Welcome, Ext user!

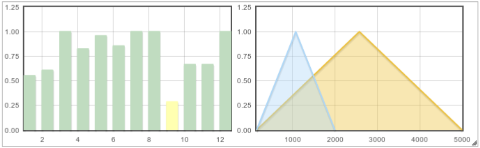
Load Save Reports Profile Help Logout

- Applicability screening
  - Field case input
  - Applicability evaluation
  - Reference intervals
- Recovery factor estimation
- Performance prediction
- Thermal recovery

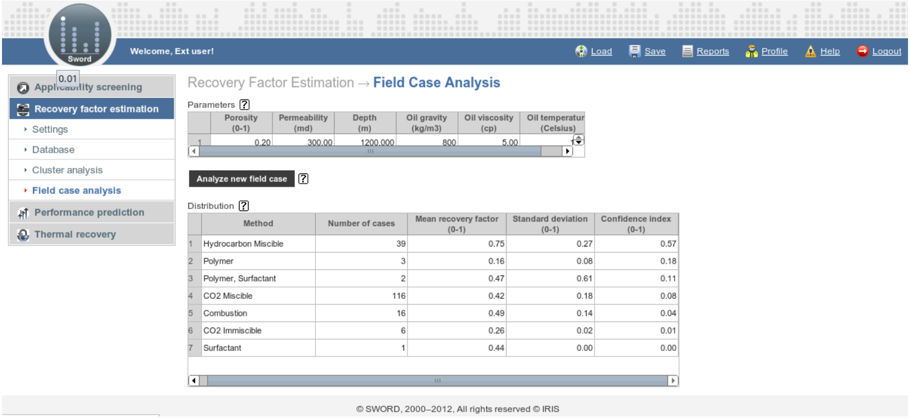
Applicability screening → **Applicability evaluation**

Method	Score	Violations
Gas injection	0.784	0
Chemical methods	0.735	0
Water flooding	0.576	0
Thermal methods	0.576	0

Parameter	Unit	User			Reference intervals			Score
		Min	Max	Comfort center	Min	Max	Comfort center	
Depth	m	150	2000	1075	150	5000	2575	0.552
Permeability	md	100	2000	1050	1	5000	2500.5	0.606
Thickness	m	6	20	13	2	130	10	0.999
Temperature	Celsius	0	70	35	0	100	50	0.824
Oil viscosity	cp	1	10	5.5	0.2	10	5.1	0.957
Pressure	bar	140	290	215	80	500	290	0.854
Oil density	kg/m3	750	850	800	650	950	800	1
Anisotropy (kv/kh)	(0-1)	0.01	0.1	0.055	0.01	0.1	0.055	1
Clay content	(0-1)	0	0.05	0.025	0	0.3	0.15	0.286
Salinity	kg/m3	0	20	10	0	40	20	0.667
Curr/init oil saturation	(0-1)	0.7	1	0.85	0.4	1	0.7	0.667
High/low perm. ratio		1	20	10.5	1	20	10.5	1



EOR: analytic screening. Worldwide database

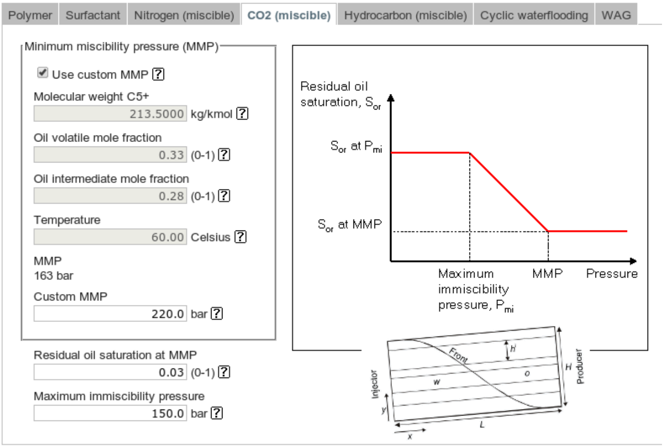


	Porosity (0-1)	Permeability (md)	Depth (m)	Oil gravity (kg/m3)	Oil viscosity (cp)	Oil temperatur (Celsius)
1	0.20	300.00	1200.000	800	5.00	

	Method	Number of cases	Mean recovery factor (0-1)	Standard deviation (0-1)	Confidence index (0-1)
1	Hydrocarbon Miscible	39	0.75	0.27	0.57
2	Polymer	3	0.16	0.08	0.18
3	Polymer, Surfactant	2	0.47	0.61	0.11
4	CO2 Miscible	116	0.42	0.18	0.08
5	Combustion	16	0.49	0.14	0.04
6	CO2 Immiscible	6	0.26	0.02	0.01
7	Surfactant	1	0.44	0.00	0.00

EOR: analytic screening. Analytical simulation

Performance prediction → **Advanced process input**



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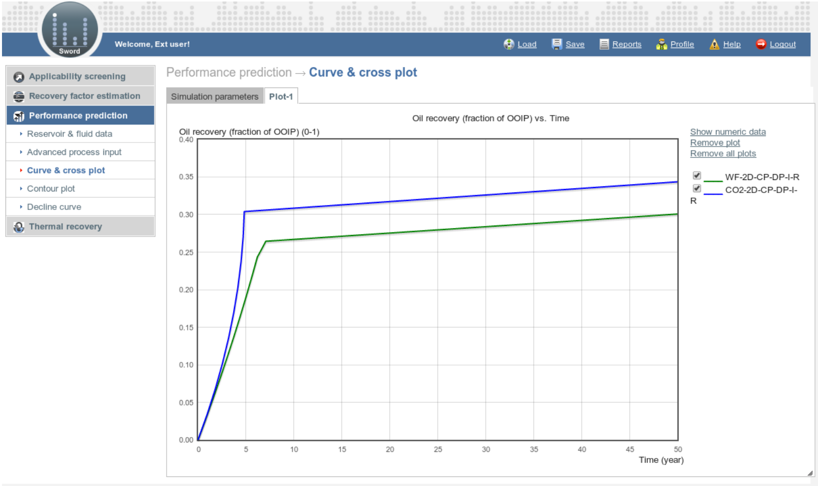

Evaluation of CO_2 injection

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As of the reservoir simulation:

- Blackoil model may be used for quick evaluation of immiscible process.
- Modern compositional simulations often allow lots of functionality. It is important:
  - Understand the physics of the process.
  - Concentrate on the governing forces and choose the tool which can handle them correctly
  - Use simpler correlations that fit to the data and knowledge you have rather than some 20-parametric model from which you can determine only 1 parameter.

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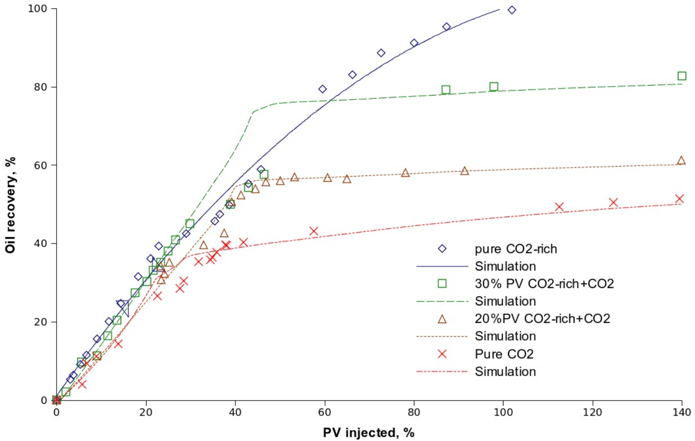
Three HC-phase flow

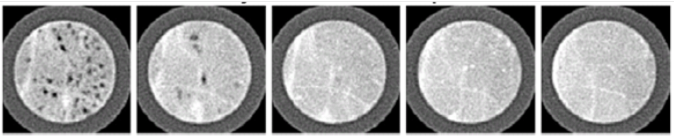
Simulating lab scale results: building block for a pilot model



Interaction with reservoir rock

Simulating lab scale results: building block for a pilot model CT-scan

core measurements in DTU showed that carbonated water creates up to 1cm long wormholes:



Yet the injectivity into the core as a function of time *decreased*

$$CaCO_3(s) + CO_2(aq) + H_2O \rightleftharpoons Ca(HCO_3)_2$$

Precipitation of $CaCO_3$ and associated pore blockage dominated over wormhole creation effect!

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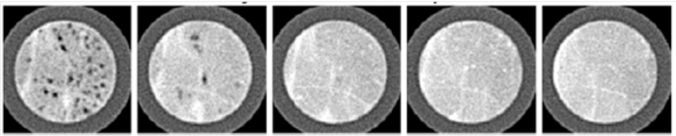

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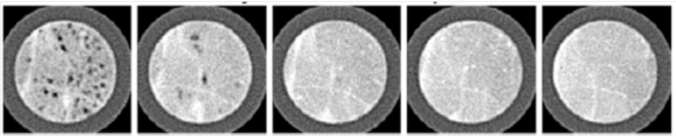

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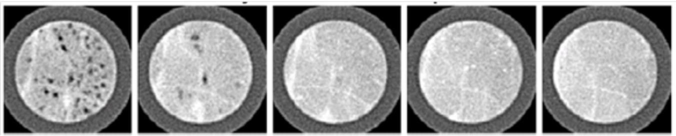

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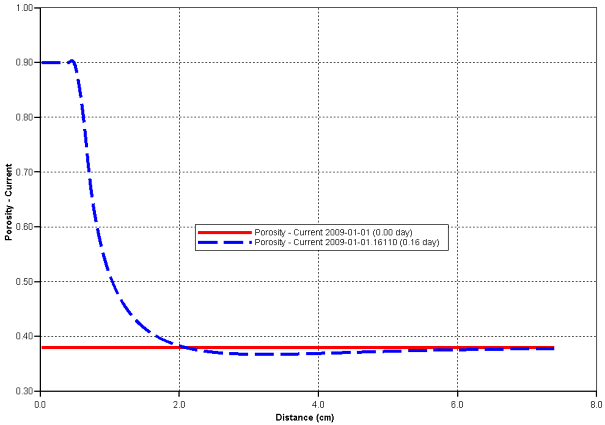
Simulating lab scale results: building block for a pilot model

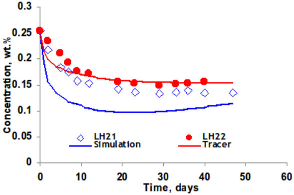
Those effects were successfully modeled with STARS:

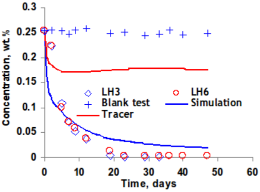


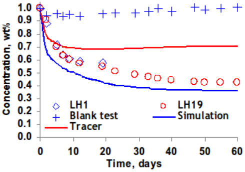
Mobility control: Foam

Simulating lab scale results: building block for a pilot model We can

simulate a large set of experiments at different conditions using the same set of simulation parameters:







C_{surf}=0.25wt %, D_{plug}=2.5cm C_{surf}=0.25wt %, D_{plug}=3.8cm C_{surf}=1.0wt %, D_{plug}=3.8cm

S_w=100%, T=55^{0}C

Questions regarding scaling those results up to reservoir level are being looked upon

Reservoir simulation: data

Complex phase behaviour requires elaborate laboratory study:

- Interaction between CO_2 and oil: miscibility development, changes in phase properties (swelling), precipitation
- If mobility control agents are to be used lab studies are needed as well
- Same goes for interaction with reservoir rock

Reservoir models **must** be tuned to reservoir data to yield reasonable predictions

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EOR: Why WAG?

IRIS

- Improved area and vertical sweep
- Improved mobility control during gas injection
- Insufficient gas resources for gas injection
- Improved microscopic displacement
- Gas disposal
- Attic oil
- Cellar oil

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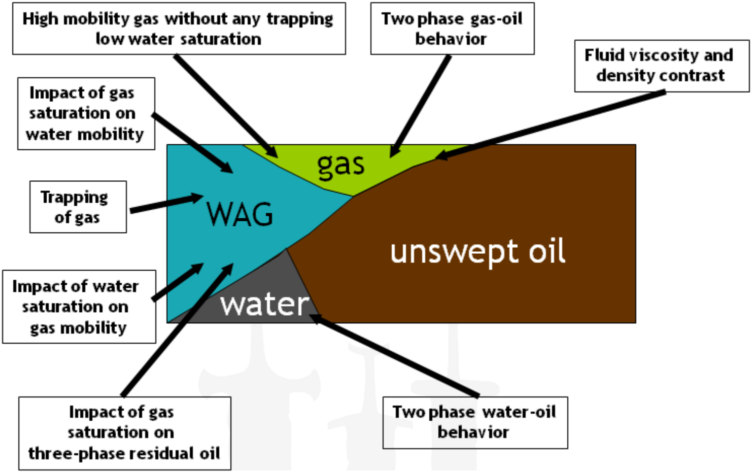
High mobility gas without any trapping
low water saturation
Two phase gas-oil
behavior
Fluid viscosity and
density contrast
Impact of gas
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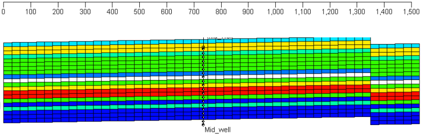
EOR Project



A compositional, dual porosity reservoir model accounting for various (viscous, gravity, capillary, diffusion forces) transfer mechanisms, solubility in water is constructed.

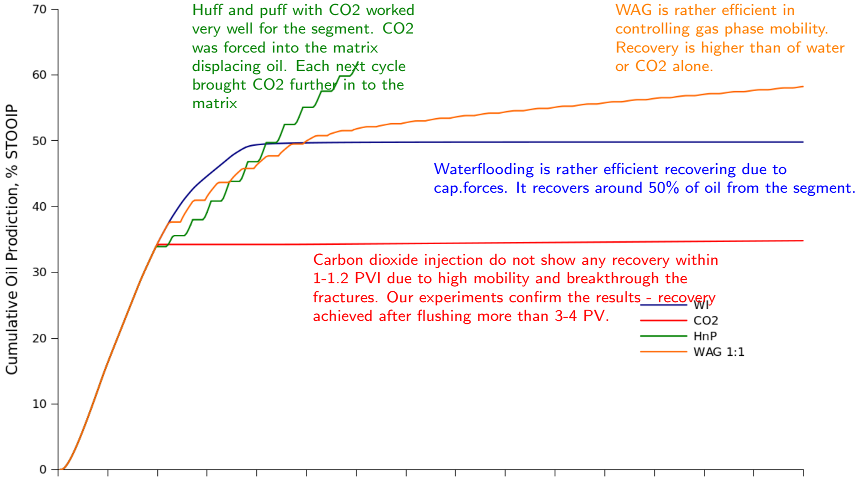
We account for changing porosity and permeability as a function of pressure.

Geochemical reactions are incorporated.

Importance of different effects is studied, different injection scenarios evaluated.

EOR Project

IRIS



EGR: Pressure support

IRIS

CO_2 can be injected (re-injected) into gas reservoir for pressure support

Gravity stable injection downflank to avoid breakthrough

Contamination of the produced gas with the CO_2 is the main risk

In case of antropogenic CO_2 stream impurities may provide additional challenge... or benefits... or both

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EGR: Hydrates

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- Thermal stimulation (energy)
- Depressurisation (loss of productivity)
- Inhibitor injection (environment, costs)
- Gas exchange:
  - ca. 60% methane could be released
  - Heat of forming CO_2 hydrates > energy consumption of CH_4 dissociation

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CBM:

- CO_2 can significantly increase recovery of methane from coal beds
- Presence of Nitrogen reduces the recovery potential
- Significant volume of CO_2 was shown to absorb prior to extended gas recovery

CO_2 could also release gas dissolved in water in some of formations.

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Concluding remarks

Both EOR and EGR may be technically and economically feasible

It is important to study and verify especially compositional variations

There are other questions remaining:

- CO_2 source (volume required is varying with time) and costs
- Materials, capacity
- Legislation

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