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Influence of oil field production life on optimal CO_2 flooding strategies: Insight from the microscopic displacement efficiency

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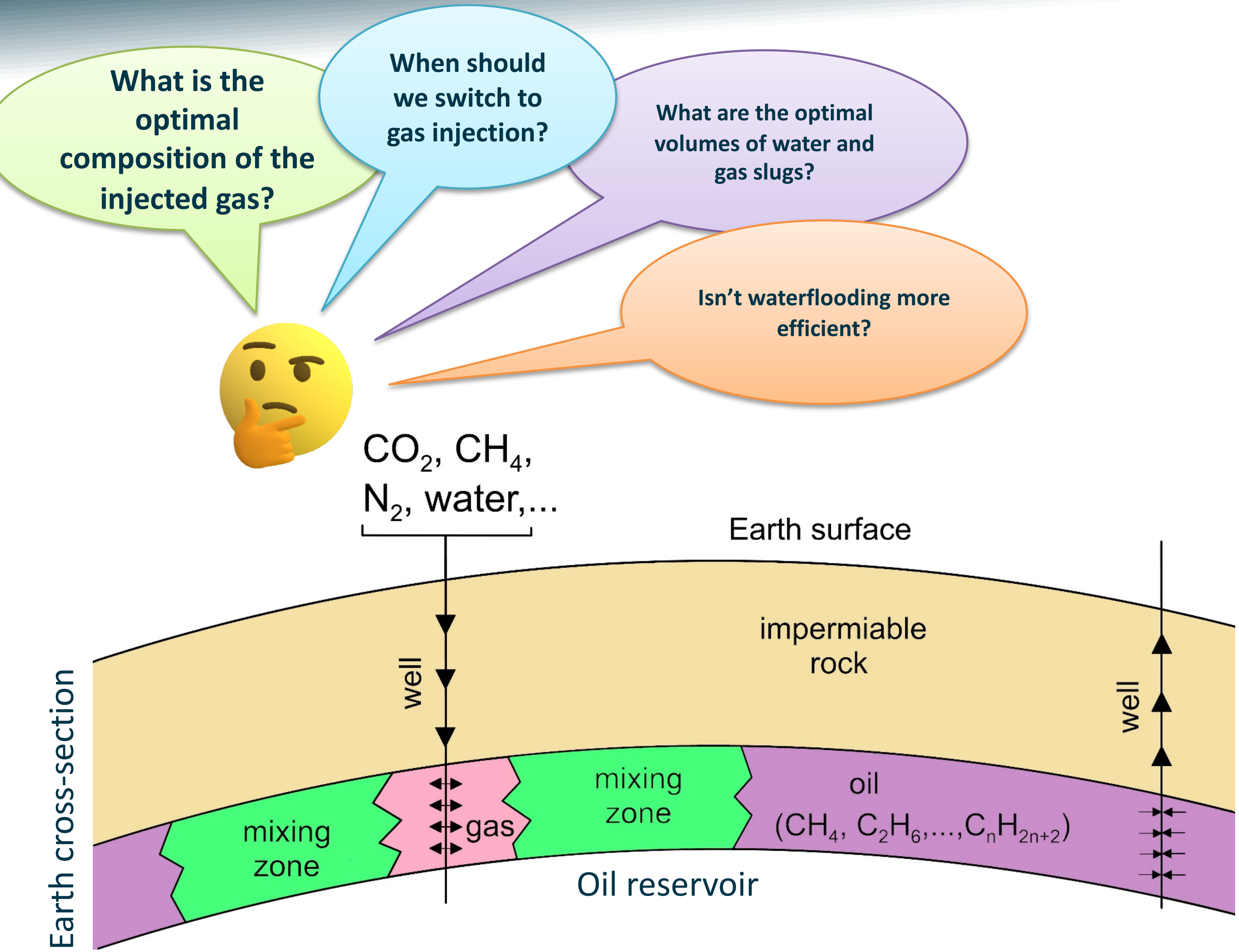
Motivation of study



- ✓ Finding optimal water and gas strategies for oil recovery
- ✓ Development of effective methods for finding optimal strategies
- ✓ Comparison of different flooding strategies efficiency by the calculations of the net present value, displacement efficiency and CO_2 storage efficiency

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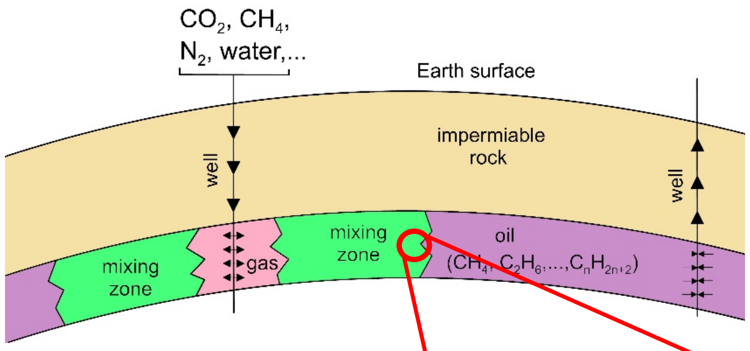
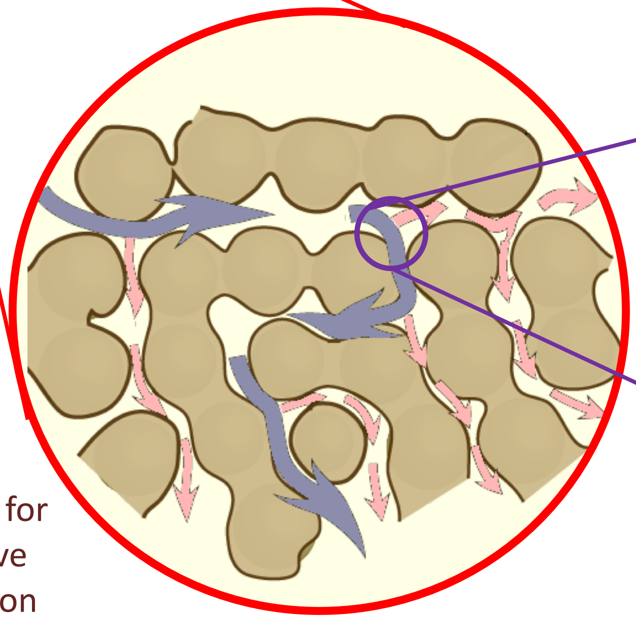
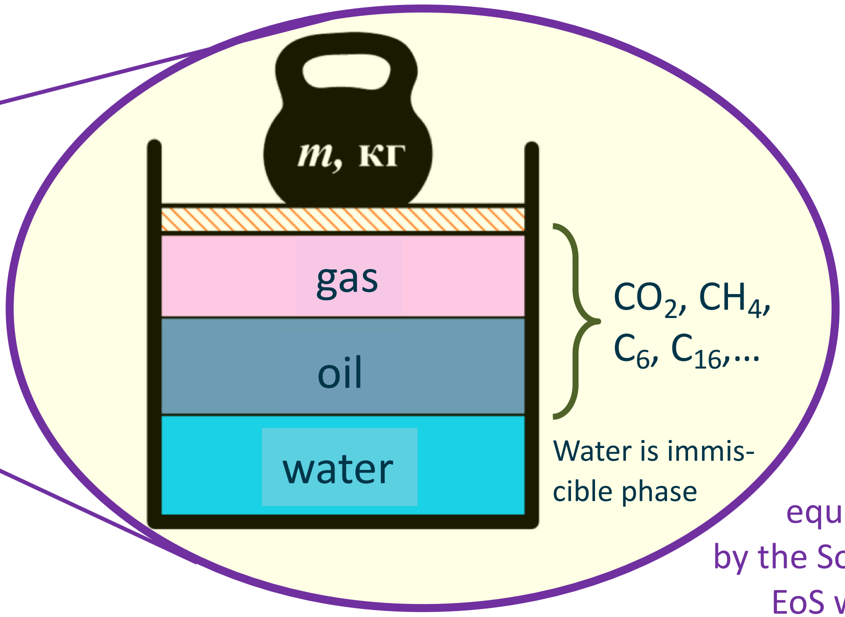
Filtration mathematical model



We use standard **compositional modeling**, which allows to calculate three-phase (water, gas and oil) flows and account for detailed fluid composition.

We use **the system of the conservation lows** for each component of the HC mixture (CO_2, CH_4, C_6, C_{16},...) and water





We use **Darsy's law** for definition of effective parameters of flow on microscopic scales

The fluid phase equilibria are predicted by the Soave-Redlich-Kwong EoS with shift correction

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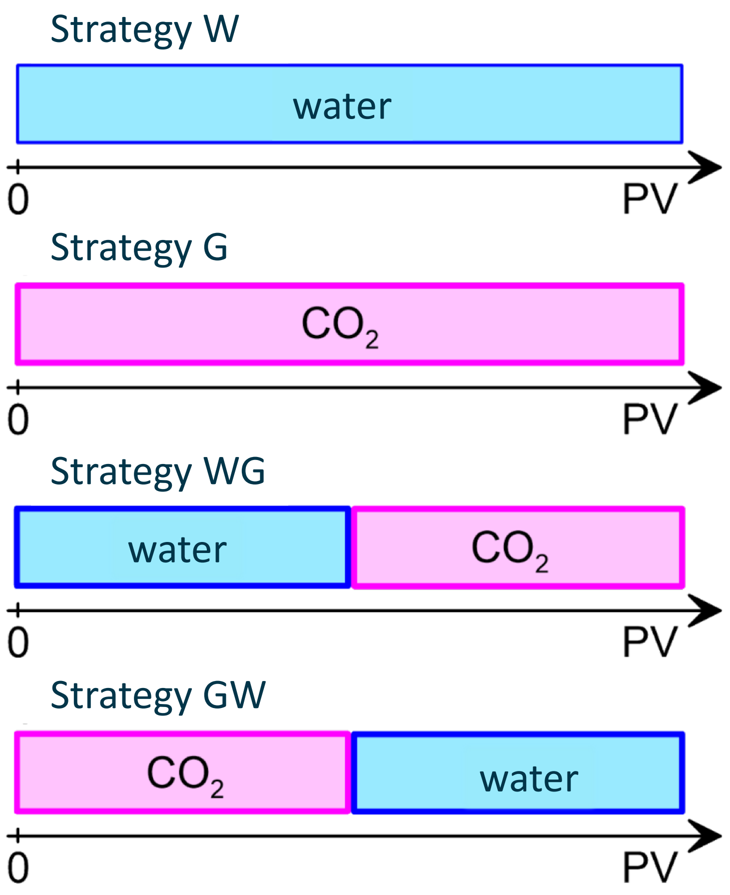
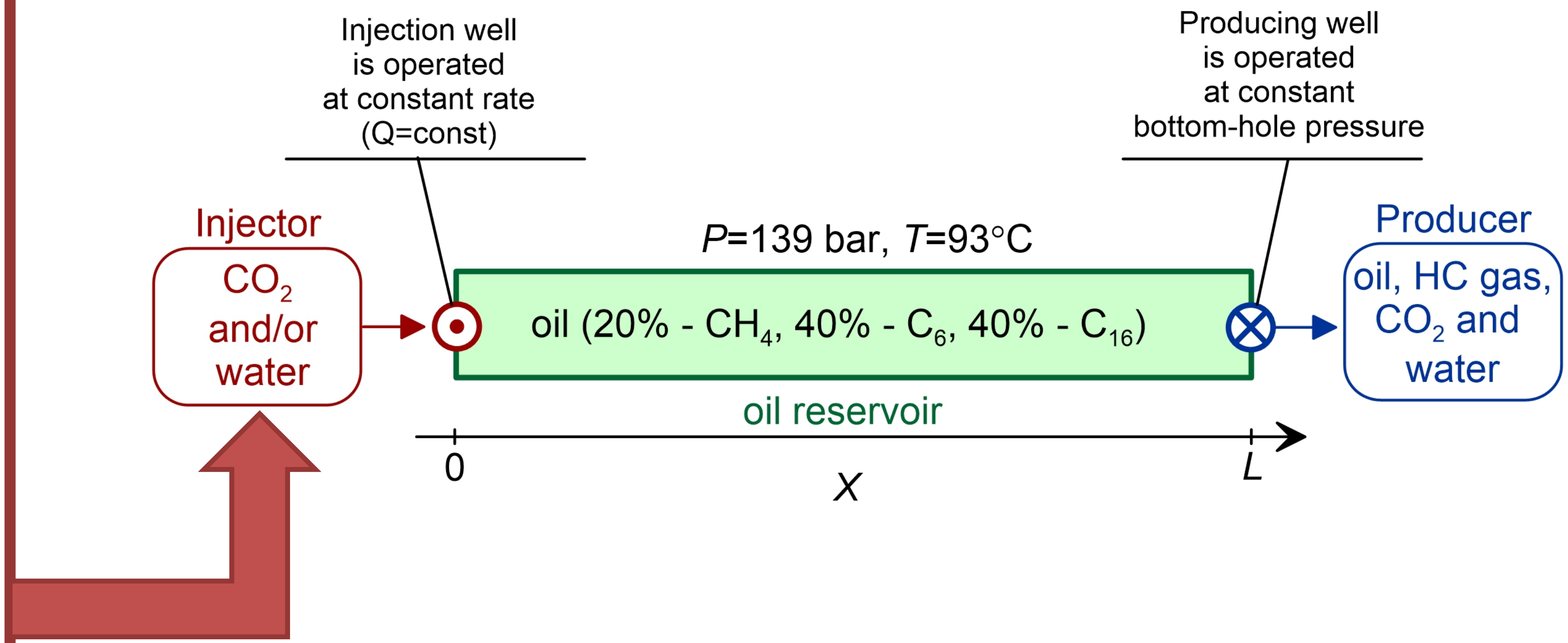
Problem statement

Injection strategies

the following strategies are considered in detail

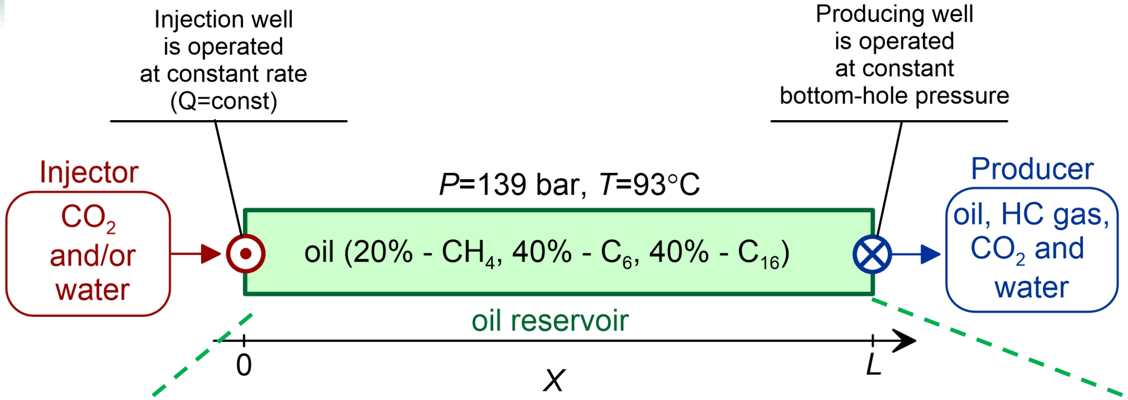


1-D simulations

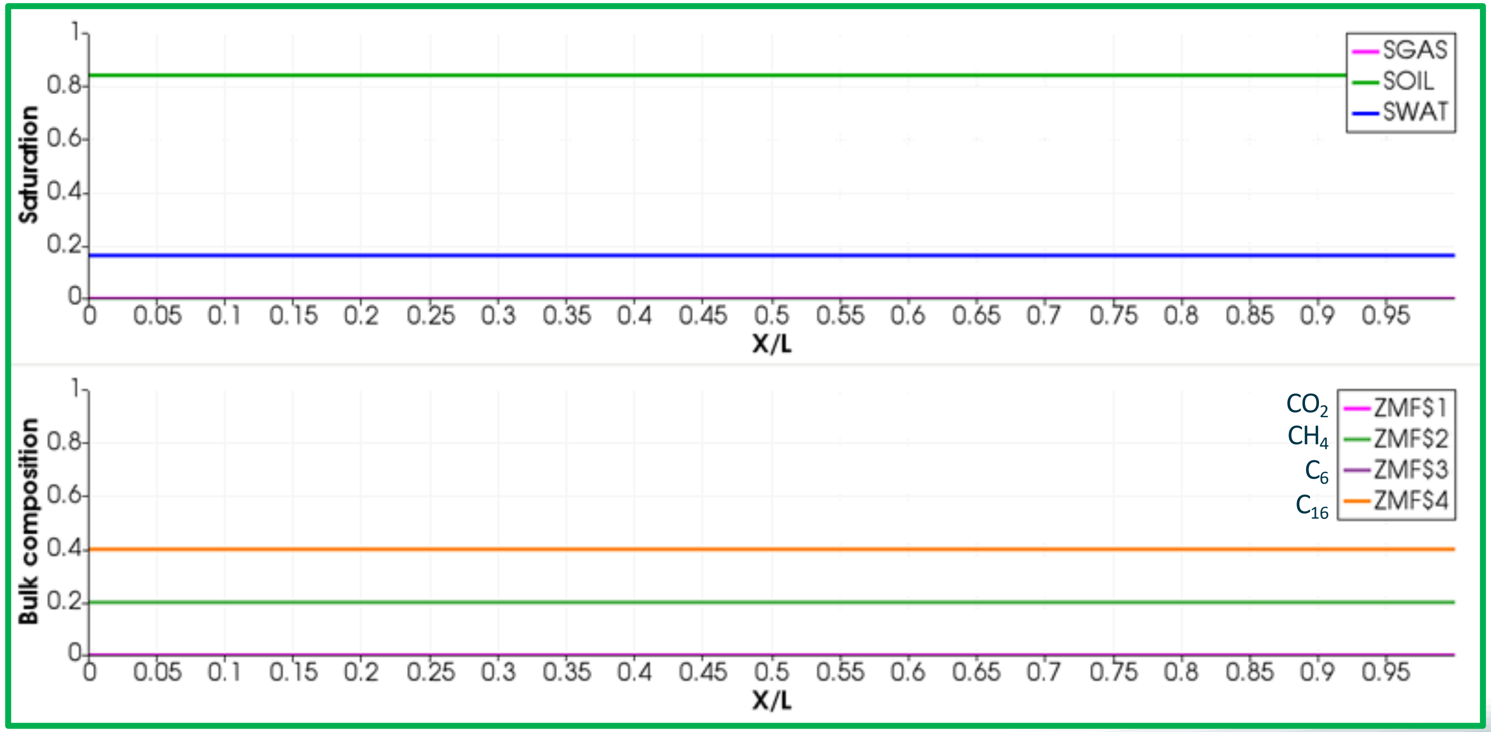


We calculate efficiency of the oil displacement in a domain of length L, i.e. $0 \le X \le L$

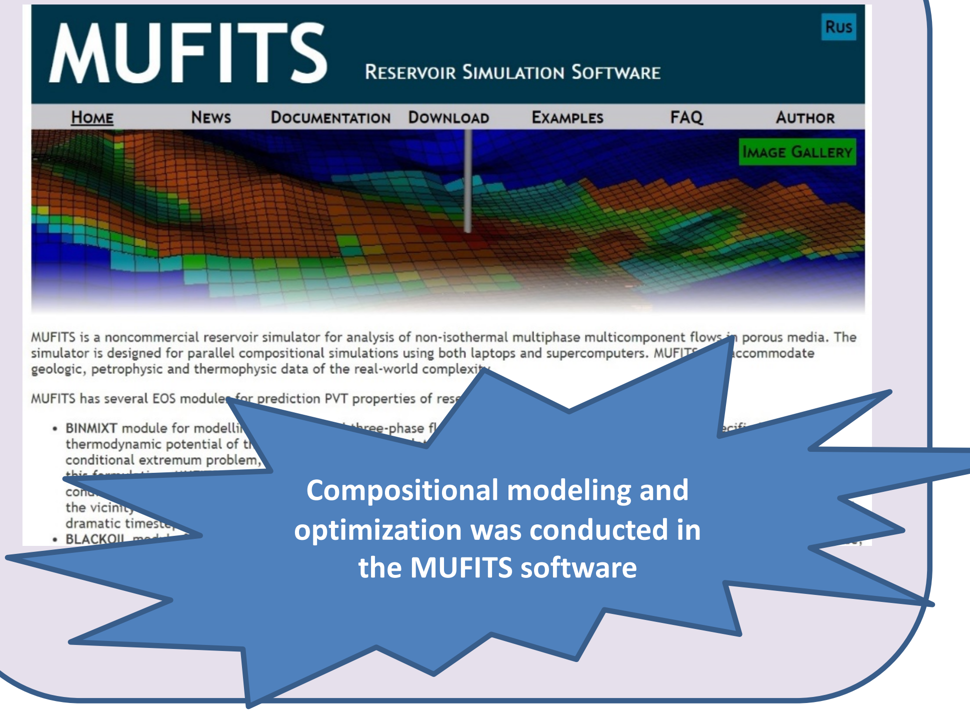
Example of optimized strategy GW



First, 0.244 pore volume CO_2 are injected, then water is injected



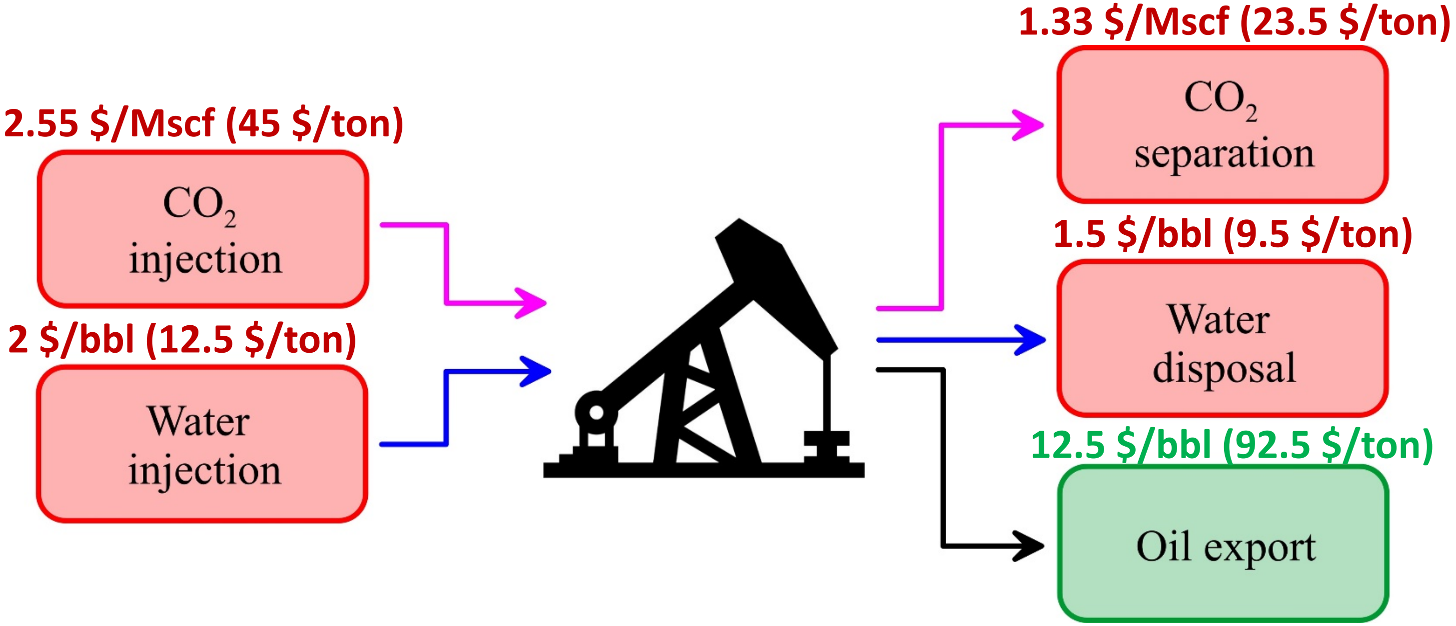
Website: www.mufits.imec.msu.ru



Gas injection optimization

Economic model

(costs are highlighted in red, net revenue from oil sale is highlighted in green)



We calculate the net present value (NPV)

$$NPV(t) = \int_0^t \frac{Income - Costs}{(1+D)^{t'/t_{ds}}} dt'$$

D is the discount rate

What to maximize?

- ✓ Net present value (NPV)
- ✓ Oil recovery
- ✓ CO_2 storage efficiency (CSE)

Different injection strategies correspond these optimization criteria

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Optimization criteria

Standard method:

$$NPV(t) \rightarrow max, \qquad \text{where} \quad t = t_{end}$$

t_{end} – the end of production time is regarded as a fixed presumed quantity

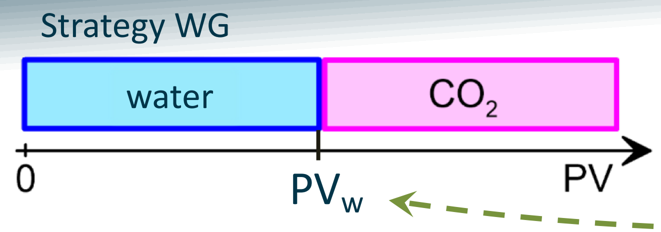
Method used in this study:

$$NPV(t) \rightarrow max, \qquad \text{where} \quad 0 \leq t < \infty$$

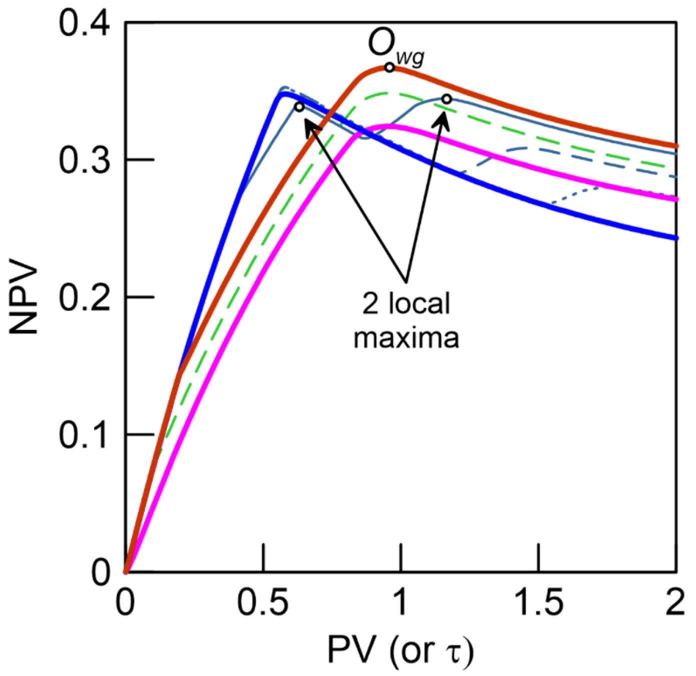
the end of production time is not fixed

We shown that in some cases
(especially at low oil prices)
this method allows to increase NPV
by 5-10%

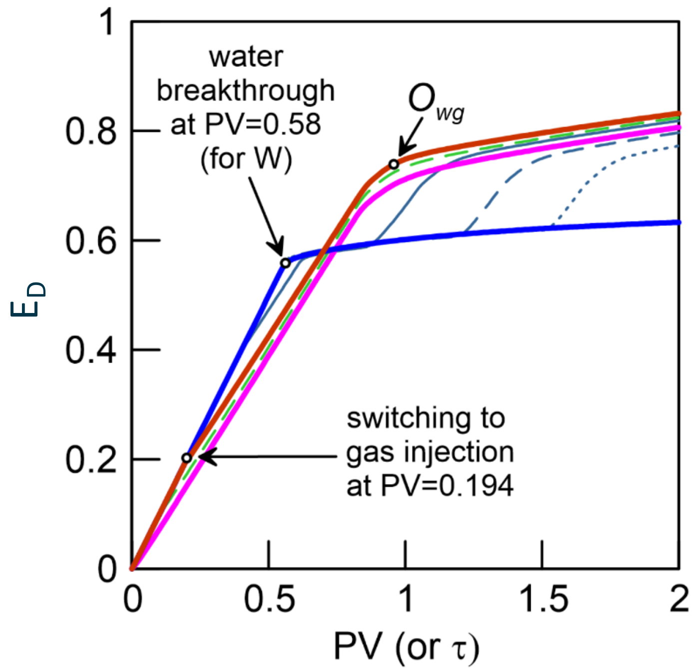
Optimizing CO_2 injection as a tertiary recovery method



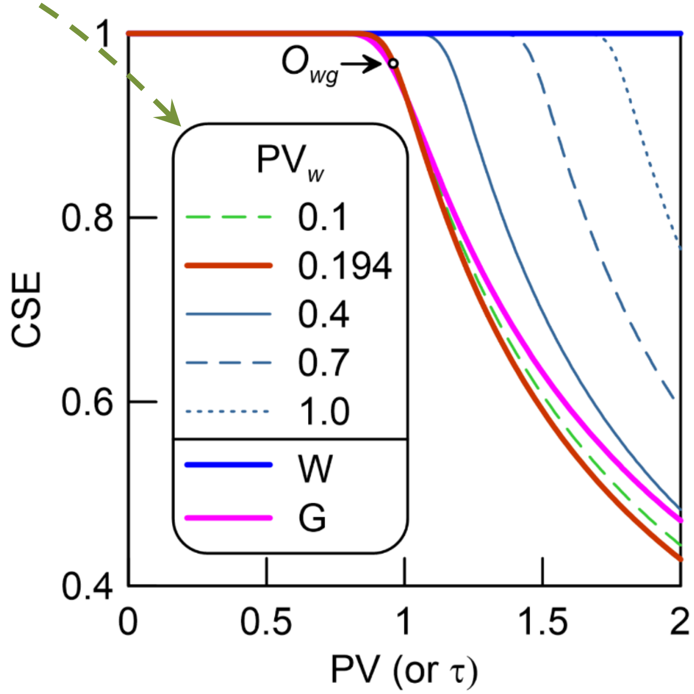
Net present value



Oil recovery



CO_2 storage efficiency



Existence of several local maxima of NPV requires specialized methods of optimization

CO_2 injection should begin earlier then when water breaks through to the Producer

Injected pore volumes (PV) or time (τ)

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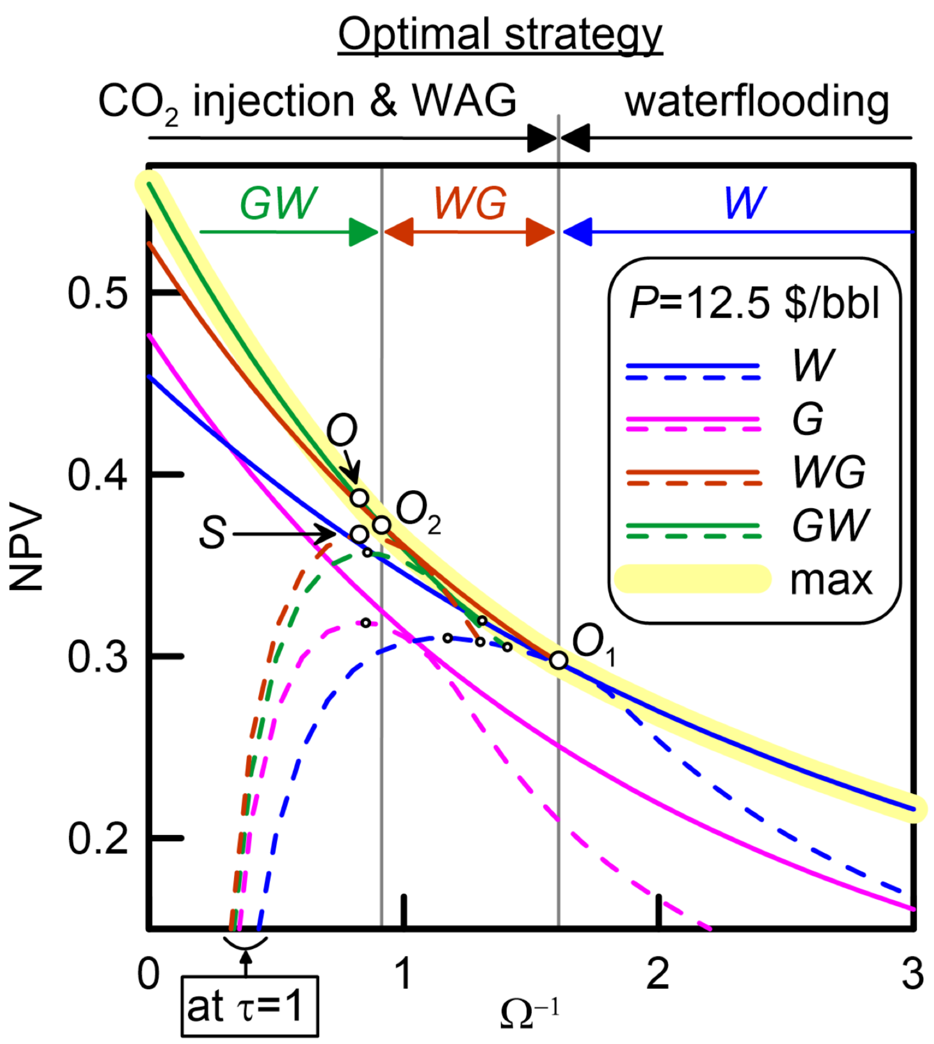
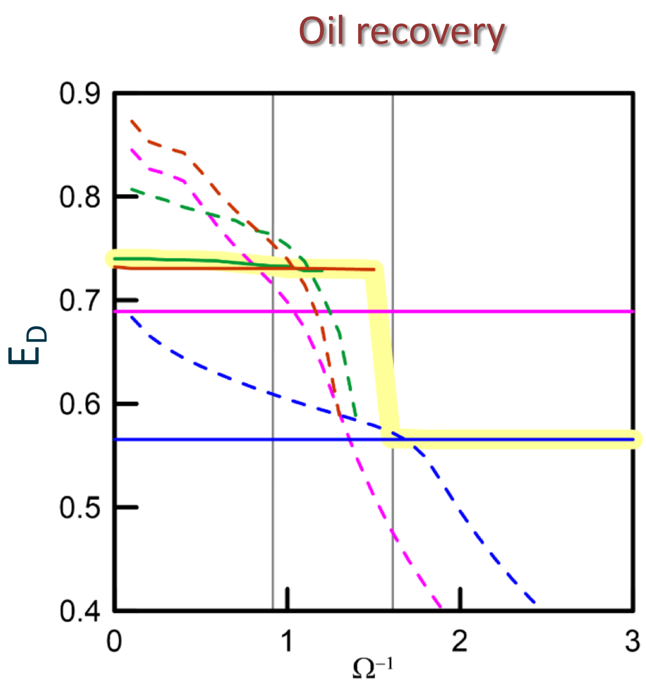
Comparison of different strategies

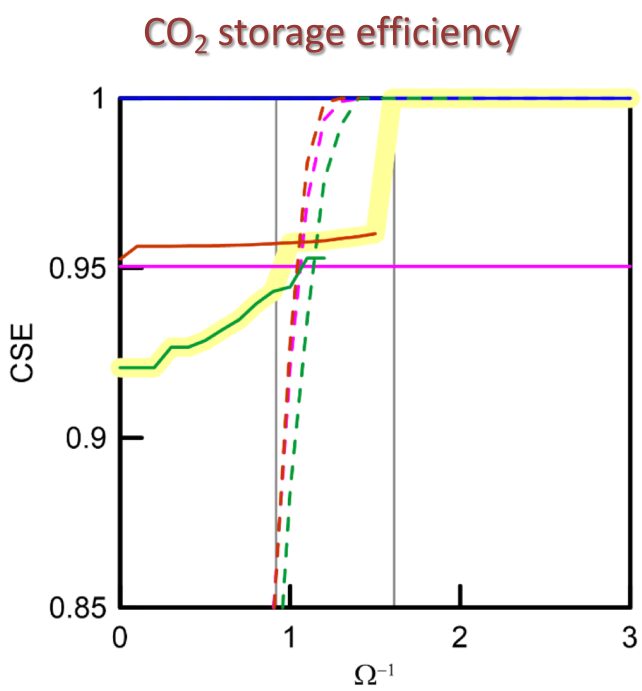


Injection rate

Fast

Slow





Gas injection is more efficient when injection rate is fast, moreover gas injection should be applied as a primary method. Waterflooding is more effective when injection rate is slow.

Ω is the dimensionless injection rate

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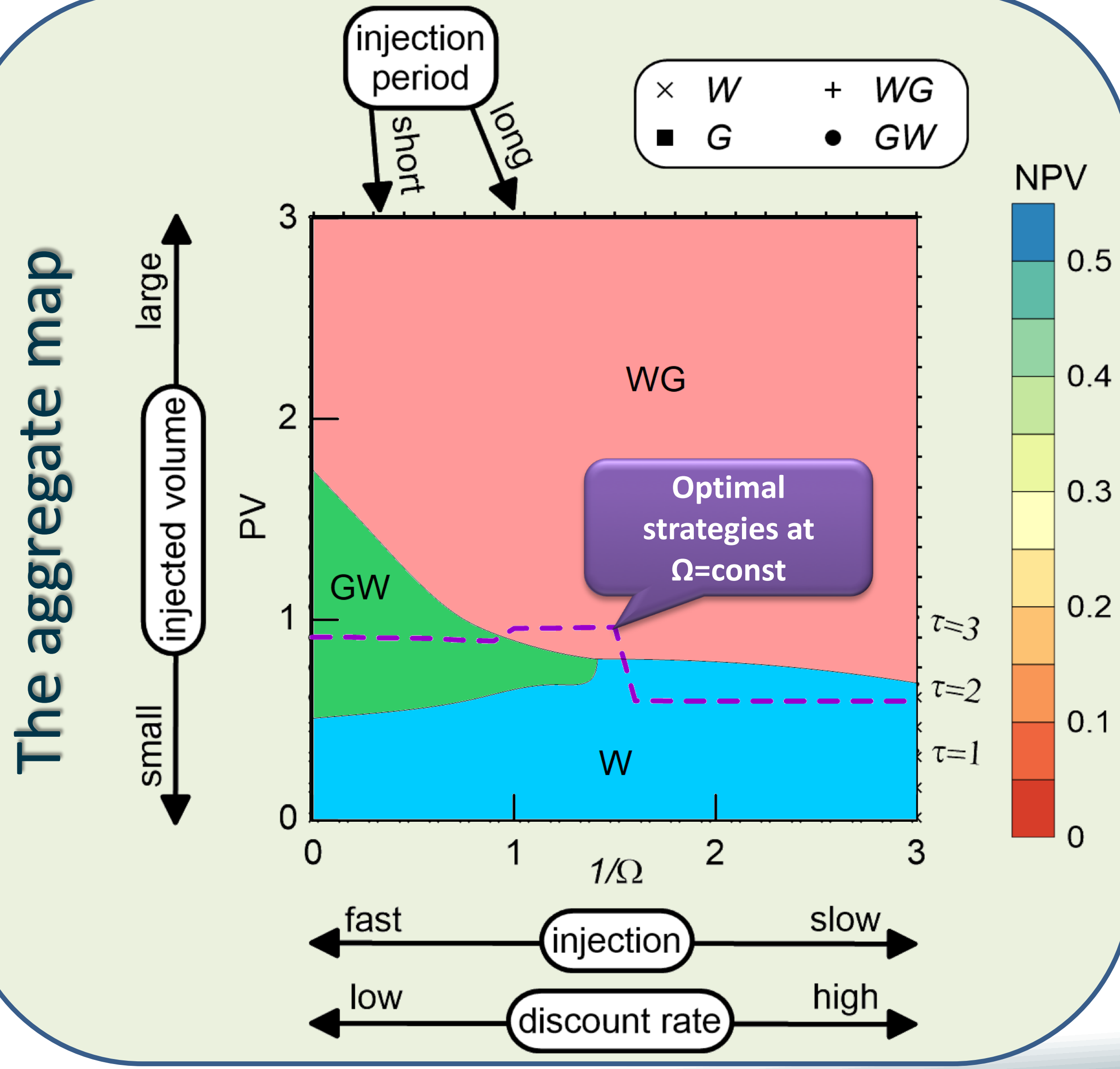
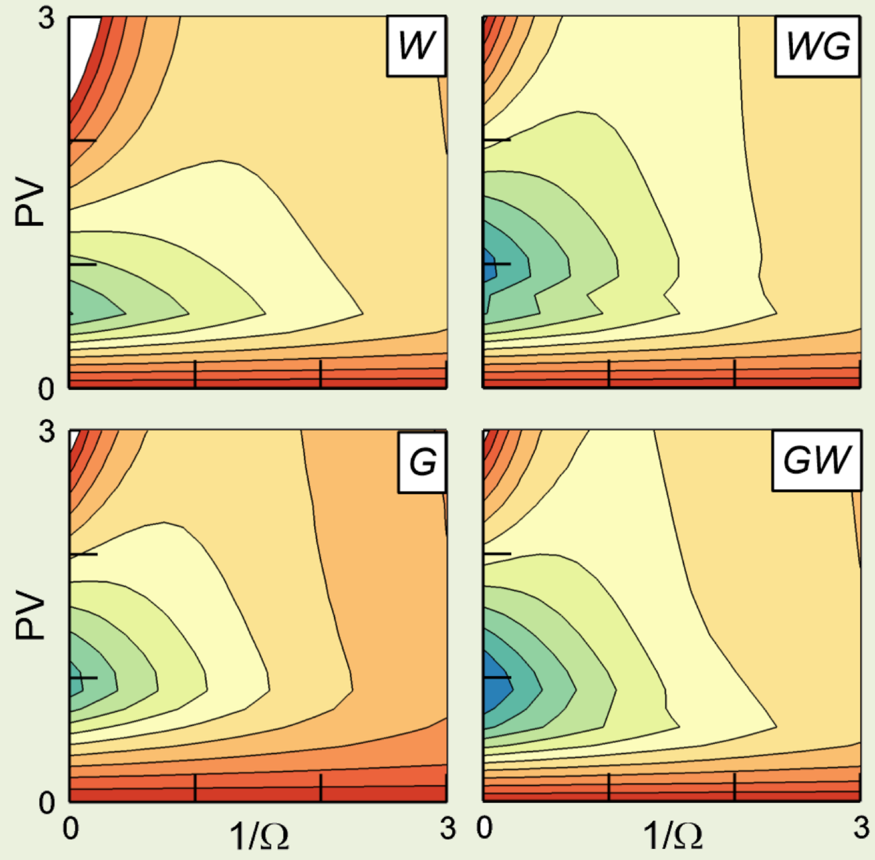
NPV map



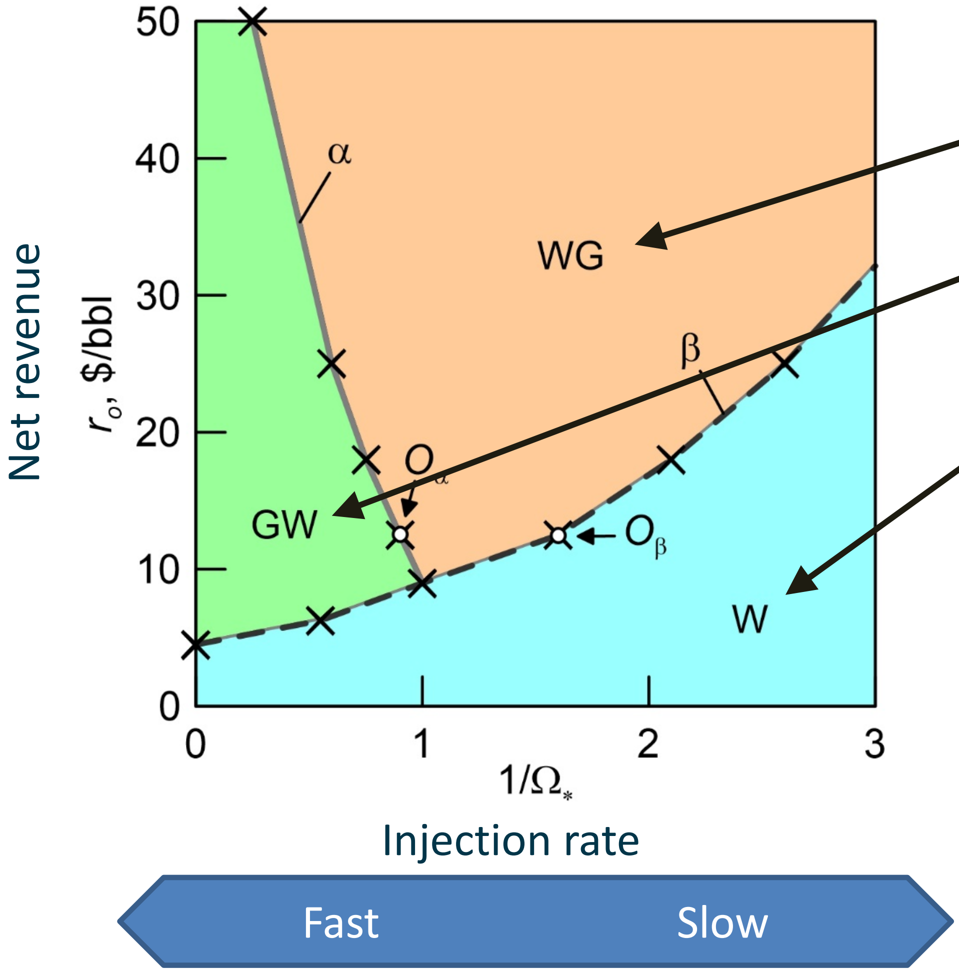
Maps for each strategy



Net revenue=12.5 $/bbl

Influence of net revenue

The map of optimal strategies



- Water slug followed by continuous CO_2 injection
- CO_2 slug followed by continuous water injection
- Waterflooding

CO_2 injection should be applied as a tertiary recovery method at oil price. CO_2 injection should be applied as a primary recovery method at a lower oil price.

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Influence of oil field production life on optimal CO_2 flooding strategies: Insight from the microscopic displacement efficiency

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ABSTRACT

We investigate the influence of the microscopic displacement processes on optimal gas flooding strategies. We couple a 1-D compositional reservoir model with an economic model of the flooding to assess profitability of the strategies. In general, we aim at the net present value maximization, although the oil recovery and CO_2 storage efficiencies are also estimated. Under certain assumptions, we reduce the number of parameters controlling selection of optimal strategy to just a few dimensionless quantities characterizing both physical and economic processes. We show that the production life of oil fields should not be fixed in optimization studies, especially at low oil prices. A significantly larger net present value can be achieved by varying the reservoir lifetime in addition to the injection rates and volumes and other well controls. Herewith, the optimal strategy can differ from that in the case of a presumed production time. We conclude that waterflooding is the optimal recovery method if the injection rate is low, whereas gas (WAG) flooding applied as a primary method and followed by waterflooding is most optimal for large injection rates. Gas flooding applied as the tertiary recovery method is most optimal for an intermediate range of the rates. In the latter case, gas injection should begin much earlier than water breaks through to producing wells. Finally, we investigate how oil price influences the range of parameters suitable for gas injection.

1. Introduction

1.1. Gas flood efficiency

Gas flooding is one of the widely used enhanced oil recovery (EOR) methods (Lake, 1989; Thomas, 2008; Alvarado and Manrique, 2010). Normally, gas injection, either continuous of alternating with water injection (WAG), is applied to reservoirs depleted after waterflooding, although there are also examples or gas injection applied as primary or secondary methods. Different hydrocarbon (HC) and non-hydrocarbon components can be injected to enhance oil recovery, and CO_2 is used most often (Brock and Bryan, 1989; Blunt et al., 1993; Christensen et al., 2001). Typically, CO_2 injection is combined with water injection in the WAG process or a CO_2 slug is chased with water. Oil recovery efficiency can be improved by $\sim 10\%$ by implementing such injection strategies. CO_2 injection can have additional merits as a sequestration strategy in places with excess amounts of anthropogenic CO_2 (Jessen et al., 2005; Holt et al., 2009; Hill et al., 2013; Hatchell and Benson, 2017; Farajzadeh et al., 2020). Thus, the injection can also be aimed at reducing emissions and mitigation of the greenhouse effect.

Gas flooding involves physical phenomena at various pore and field scales, which have been discussed in detail and reviewed by Lake (1989), Pritchard and Nieman (1992), Johns et al. (2003), Johns and Dindoruk (2013), among others. The efficiency of oil recovery by a gas flood, E_R, is often estimated as

$$E_R = E_V E_D \tag{1}$$

where E_V is the volumetric sweep efficiency and E_D is the microscopic displacement efficiency (Ghedan, 2009; Verma, 2015). The quantity E_V characterizes the fraction of hydrocarbon pore space that comes in contact with injected gas. Unfavorable gas-to-oil mobility ratio, gravity override and channeling can result in a significant volume of bypassed oil and thus, poor sweep efficiency. The WAG process aims at reducing these phenomena (Pritchard and Nieman, 1992; Sanchez, 1999; Jensen et al., 2012; Johns and Dindoruk, 2013).

The quantity E_D characterizes the displacement efficiency solely at the pore scale. One of the most critical parameters influencing E_D is the minimum miscibility pressure (MMP). At such pressures a high micro-

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Summary

- ✓ Maximization of the net present value (NPV), oil recovery (E_D) of CO_2 storage efficiency (CSE) lead to different optimal water-gas strategies
- ✓ Variation of the end of production time allows to increase NPV by 5-10% as compared to the case of a fixed production time
- ✓ The objective function, NPV, may have some local maxima. Consequently, robust optimization methods must be applied in the optimization
- ✓ In the case of gas injection as a tertiary method, the gas flooding should begin earlier than the time of the water breakthrough into the producing wells
- ✓ Gas injection is more efficient at high injection rates. Moreover, gas injection should apply as a primary method. Waterflooding is more efficient if the injection rate is low.

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