The solvent model for CO2-EOR simulations

OPM meeting in Oslo
Why CO2-EOR?

- PARIS COP21
- IEA: CO2-EOR - a stepping stone for CCS
- OG21 strategy: Make CO2 available offshore for EOR and/or storage

KLIMAGASSUTSLIPP FRA OLJE- OG GASS VIRKSOMHET I 2013
Utslip til luft (millioner tonn CO2-ekvivalenter)

- Energioproduksjon
  - 11,0
- Børntesting
  - 0,1
- Oljelasting
  - 0,2
- Fakling
  - 1,3
- Andre kilder
  - 1,3
- Flyttbare innretninger
  - 1,3

Totale klimagassutslipp

- Olje og gass
  - 13,9
- Industri
  - 12,1
- Transport
  - 17,1

Figures viser tall som rapporteres til FN s klimakonvensjon i oktober 2015.
Kilde: Miljødirektoratet 2015 / Miljøstatus.no
CO2-EOR. How does it work?

› Multi-contact miscible displacement

› CO2 → OIL (Condensing)
  • Swelling of the oil phase
  • Reduces viscosity of the oil
  • Increases density of oil (brings it closer to water)

› OIL → CO2 (Vaporization)
  • Extraction of lighter hydrocarbons
  • Increases viscosity of the gas

› Lowers the interfacial tension between the CO2 rich gas phase and the oil phase. → lower residual oil saturation.

› Forms single phase locally at minimum miscibility pressure (MMP)

› Dispersion

› CO2 → Water (Dissolve)
Why extended black-oil (solvent) simulator?

› Gas and oil is represented by three-pseudo components (oil, solution gas, and injected solvent)
› Effective hydrocarbon relative permeability and viscosity.

› PROS
  • Use existing blackoil models.
  • Computationally more efficient than compositional simulators.

› CONS
  • Can we trust the results?

31 May 2016
Model formulation

- Effective hydrocarbon relative permeability

\[
\begin{align*}
  k_{roe} &= M \cdot \left( \frac{s_o - s_{or}}{s_n - s_{gc} - s_{or}} \right) \cdot k_{rn} + (1 - M) \cdot k_{ro} \\
  k_{r*e} &= M \cdot \left( \frac{s_g + s_s - s_{gc}}{s_n - s_{gc} - s_{or}} \right) \cdot k_{rn} + (1 - M) \cdot k_{r*}
\end{align*}
\]

\[ *
\]

\[ = g : \quad k_{rg} = \frac{s_g}{s_g + s_s} k_{rg} (S_s + S_g) \text{ (gas component)} \]

\[ = s : \quad k_{rs} = \frac{s_s}{s_g + s_s} k_{rg} (S_s + S_g) \text{ (solvent component)} \]

\[ M = M(\text{pressure, solvent fraction}) \text{: Miscibility function} \]

\[ k_{ro} : \text{oil rel.perm} \]

\[ k_{rg} : \text{gas rel.perm} \]

\[ k_{rn} : \text{hydrocarbon to water rel.perm} \]

\[ S_{or} : \text{residual oil saturation} \]

\[ S_{gc} : \text{critical gas saturation} \]

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Model formulation

› Effective viscosities
  • \( \mu_{oe} = \mu_o^{1-\omega} \cdot \mu_{mos}^{\omega} \)
  • \( \mu_{se} = \mu_s^{1-\omega} \cdot \mu_m^{\omega} \)
  • \( \mu_{ge} = \mu_g^{1-\omega} \cdot \mu_{msg}^{\omega} \)

\( \mu_{mos} \): fully mixed viscosity of oil and solvent (using the ¼ power mixing rule)
\( \mu_m \): fully mixed viscosity of oil, gas and solvent (using the ¼ power mixing rule)
\( \mu_{msg} \): fully mixed viscosity of solvent and gas (using the ¼ power mixing rule)
\( \omega \): is the Todd-Longstaff mixing parameter

› Other effects
  • Effective densities
  • Modified residual oil saturation / critical gas saturation
  • Pressure effects on capillary pressure, viscosity and density miscibility
  • Pressure dependent Todd-Longstaff parameter
Comparison SPE 5:

- Comparison of 4-component miscible simulators and compositional simulators
- Three cases. Where average reservoir pressure is:
  1. Much lower than MMP (immiscible case)
  2. Near or above MMP
  3. Below first, new MMP after re-pressurizing
Comparison SPE 5: (OPM-FLOW, Eclipse)

SPE 5 case 1: With no mixing effect on the densities
Comparison SPE 5: (OPM-FLOW, Eclipse)

SPE 5 case 2

SPE 5 case 3
Field scale simulations

- **Setup**
  - Run 5295 days of history.
  - Group controlled production wells.
  - CO2 injected from day 5479
  - Linear ramp between 100-250 Barsa to model pressure dependency in the miscibility
  - The pressure dependency in the Todd-Longstaff parameter is neglected.

After 0.5 years of CO2 injection

After 12 years of CO2 injection
Field scale simulations (OPM-FLOW, Eclipse)
Field scale simulations (OPM-FLOW, Eclipse)

well-10:WBHP

well-10:WGIR
Field scale simulations (OPM-FLOW, Eclipse)

- **well-12:WBHP**
  - Graph showing pressure over days.
- **well-12:WOPR**
  - Graph showing production rate over days.
- **well-12:WGPR**
  - Graph showing injection pressure over days.
- **well-12:WWPR**
  - Graph showing water production rate over days.
Summary

› FLOW-SOLVENT. Extended black-oil model for CO2-EOR simulations
› Benchmarked against Eclipse
› New feature implemented. Pressure depended Todd-Longstaff parameter.

Discussion:
• Can the relevant CO2-EOR physics be modeled using an extended black-oil (solvent) model?
• How to determine the Todd-Longstaff parameter?