Prozessverständnis, Modelle und Simulationswerkzeuge

Reservoir modelling and simulation

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Motivation for stimulation simulation

- **Pre-stimulation:**
  - planning / design of optimum fracture treatment according to the reservoir characteristics
  - characterisation of “key” reservoir parameter

- **Post-stimulation:**
  - quantification of induced fracture dimensions (beside seismic)
  - calculation of fold of increase (FOI) after the stimulation treatment with respect to the productivity index PI
water / low viscous gels: \( \eta = 1 - 10 \text{ cP} \)
without proppants or small proppant concentration: \( c = 50 - 200 \text{ g/l} \)
long fractures: \( x_f \leq 250 \text{ m} \)
small width: \( w_f \sim 1 \text{ mm} \)

- reduction in costs compared or HPF
- application is limited to reservoirs with small permeability
- success is dependent on the self propping potential of the reservoir rock

Introduction - Hydraulic stimulation technique: waterfracs (WF)
high viscous gels: \( \eta = 100 - 1000 \text{ cP} \)

high proppant concentration: \( c = 200 - 2000 \text{ g/l} \)

shorter fractures: \( x_f = 50 - 150 \text{ m} \)

big width: \( w_f = 5 - 25 \text{ mm} \)

• wide range of formations (permeabilities) can be treated

• good control of stimulation parameters

• wellbore skin can be bypassed

• treatments are more expensive

Introduction - Hydraulic stimulation technique: hydraulic proppant fracs (HPF)
1. two dimensional with constant radius (penny-shaped models)
2. with constant fracture height (PKN, Perkins and Kern, 1961, Nodgren, 1972)
3. cell-based pseudo 3D models
4. lumped parameter 3D models
5. real planar 3D models have been developed (Mack and Warpinski, 2000).
- 2 km x 2 km
- Crystalline fractured reservoir
- Anisotropic in-situ stress
- $S_H = 75$ MPa, $S_h = 60$ MPa
- Fluid injection at centre
- 1 cP viscosity
- 1D injection, 1.5D shut-in
- BHP controlled injection
Yoon, Zang, Stephansson (2012)

\[
\begin{align*}
T &= 16.65 \text{ hr.} \\
T &= 33.32 \text{ hr.} \\
T &= 52.81 \text{ hr.}
\end{align*}
\]

* \( \text{dt} : 8.4 \text{ sec.} \)

Black: Mode I rock failure
Red: Mode II rock failure
Blue: Mode I joint failure
Pink: Mode II joint failure
Overview - fracture models

\[ V_{\text{inj}} = V_{\text{leakoff}} + V_{\text{frac}} \]
### Sensitivity analyses - reservoir parameter

<table>
<thead>
<tr>
<th><strong>INPUT</strong></th>
<th><strong>OUTPUT</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Permeability [mD]</td>
<td>Frac length [m]</td>
</tr>
<tr>
<td>Porosity [%]</td>
<td>Frac height [m]</td>
</tr>
<tr>
<td>Closure Pressure [MPa]</td>
<td>Frac area [m²]</td>
</tr>
<tr>
<td>Closure Pressure Gradient [MPa/m]</td>
<td>Aperture [m]</td>
</tr>
<tr>
<td>Youngs Modulus [GPa]</td>
<td>Well head pressure [MPa]</td>
</tr>
<tr>
<td>Poissons Number [-]</td>
<td></td>
</tr>
<tr>
<td>Pore Pressure [MPa]</td>
<td></td>
</tr>
<tr>
<td>Fluid Viscosity [mPa s]</td>
<td></td>
</tr>
<tr>
<td>Fracture Toughness [MPa m^{1/2}]</td>
<td></td>
</tr>
<tr>
<td>Parameter</td>
<td>Value</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Permeability [mD]</td>
<td>0.2 mD</td>
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<tr>
<td>Porosity [%]</td>
<td>0.2%</td>
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<tr>
<td>Closure Pressure [MPa]</td>
<td>46 MPa</td>
</tr>
<tr>
<td>Young's Modulus [GPa]</td>
<td>80 GPa</td>
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<tr>
<td>Poisson's Number [-]</td>
<td>0.3</td>
</tr>
<tr>
<td>Pore Pressure [MPa]</td>
<td>39 MPa</td>
</tr>
<tr>
<td>Fluid Viscosity [mPa s]</td>
<td>0.264 mPas</td>
</tr>
<tr>
<td>Fracture Toughness [MPa m^{1/2}]</td>
<td>17 MPa m^{1/2}</td>
</tr>
</tbody>
</table>

Sensitivity analyses – fracture area
Sensitivity analyses – fracture aperture

- Permeability [mD]
- Porosity [%]
- Closure Pressure [MPa]
- Young's Modulus [GPa]
- Poisson's Number [-]
- Pore Pressure [MPa]
- Fluid Viscosity [mPa s]
- Fracture Toughness [MPa m^1/2]

Values shown in the graph include:
- 0.5mD
- 2.5%
- 46MPa
- 56GPa
- 0.2
- 39MPa
- 0.264mPas
- 70MPa
- 0.5mD
- 10%
- 55GPa
- 10GPa
- 35MPa
- 220mPas
- 17MPa m^1/2
- 17mD
- 10MPa m^1/2
Sensitivity analyses – well head pressure

- Permeability [mD]
- Porosity [%]
- Closure Pressure [MPa]
- Young's Modulus [GPa]
- Poisson's Number [-]
- Pore Pressure [MPa]
- Fluid Viscosity [mPa s]
- Fracture Toughness [MPa m^{1/2}]

Values:
- Permeability: 0.2 mD, 50 mD
- Porosity: 0.2%, 10%
- Closure Pressure: 58 MPa, 46 MPa
- Young's Modulus: 80 GPa, 10 GPa
- Poisson's Number: 0.3, 0.2
- Pore Pressure: 39 MPa, 35 MPa
- Fluid Viscosity: 0.264 mPas, 0.220 mPas
- Fracture Toughness: 17 MPa m^{1/2}, 10 MPa m^{1/2}
## Sensitivity analyses - results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Length</th>
<th>Height</th>
<th>Width</th>
<th>Wellhead pressure</th>
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<tbody>
<tr>
<td><strong>Leak-off parameters</strong></td>
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<tr>
<td>Permeability</td>
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<td>---</td>
<td>-</td>
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<tr>
<td>Porosity</td>
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<td>+</td>
<td>0</td>
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<tr>
<td>Pore pressure</td>
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<td>+</td>
<td>+</td>
<td>0</td>
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<tr>
<td>Fluid viscosity</td>
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<tr>
<td><strong>Mechanical parameters</strong></td>
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<tr>
<td>Young’s modulus</td>
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<td>++</td>
<td>---</td>
<td>+++</td>
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<tr>
<td>Stress</td>
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<td>---</td>
<td>--</td>
<td>+++</td>
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<tr>
<td>Poisson’s number</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Fracture toughness</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<td><strong>Treatment parameter</strong></td>
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<td>Flow rate</td>
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<tr>
<td>Injection volume</td>
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<td>+</td>
<td>+</td>
<td>0</td>
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</tbody>
</table>
Increase of productivity - model implementation
Increase of productivity - model implementation

Time: 4567884556.1 sec
Increase of productivity - results

- $FOI = \frac{PI_{postfrac}}{PI_{prefrac}}$
- the higher matrix permeability the lower productivity increase
- 2-3 times productivity increase
• hydraulic fracturing simulations give a first idea about the expected wellhead pressures and the expected range of fracture geometries assuming the tensile opening

• potential productivity enhancement is provided by the reservoir simulations

• productivity enhancements between 2 and 3 were shown to be possible for most of the scenarios

• sensitivity analysis of the reservoir parameters showed the importance of a detailed knowledge about permeability, porosity, Young’s modulus and stress state

• important zones with high fluid leak-off and closure pressure need to be identified

• increase in flow rate increases especially fracture width and height

• increase of injection volume mainly increases the fracture half-length