Well Stimulation Techniques for Geothermal Projects in Sedimentary Basins

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Sponsored by:

Dutch Geothermal Research Agenda (Kennisagenda Aardwarmte)
This report has been made possible by the Kennisagenda subsidy of the Ministry of Economic Affairs, LTO Glaskracht Nederland and the program Kas als Energiebron.
What is well stimulation?

Any activity that enhances productivity of a well by affecting the near well bore area

- Matrix treatments – restore natural productivity
- Hydraulic fracturing – enhance natural productivity
- Acoustic methods – remove near wellbore damage
- (Re)Perforation?

What is it not?

- Reservoir enhancement like steam drive or water flooding
- Removal of scale, wax, etc. from the tubing
Determine skin factor

Skin is a dimensionless representation of near well-bore pressure drop caused by damage, plugging, etc.

Total skin $S$ (and $kh$) can be measured in a welltest.

$$\Delta P_{\text{skin}} = \frac{Q \cdot \mu}{2 \pi \cdot kh} \cdot S$$
Production & Skin: Semi-Steady State

Skin

<table>
<thead>
<tr>
<th>Production (zero skin = 100%)</th>
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<tbody>
<tr>
<td>&gt;5 &lt; 50%</td>
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<tr>
<td>2 80%</td>
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<tr>
<td>0 100%</td>
</tr>
<tr>
<td>-2 140%</td>
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<tr>
<td>-4 250%</td>
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Flow Efficiency (FE or WIQI)

\[
WIQI = \frac{Q_{damage}}{Q_0} = \frac{7}{7 + S_{damage}}
\]

Production increase after treatment

\[
PIF = \frac{7 + S_{before}}{7 + S_{after}}
\]
Causes of Damage

Damage in near borehole reservoir (injector and/or producer) or screen plugging

- Initial damage because of drilling mud or wrong treatment
- Initial damage because of wrong treatment
- Production of fines
- Injection of particles (corrosion, fines, wallskin, scaling particles)
- Scaling

Consequence

- increased drawdown in producer à more pump energy needed
  + less optimal ESP design (efficiency, depth)
- Increased injection pressure in injector à more pump energy needed + closer to max. injection criterium
Productivity improvement

- For the injection well it means **higher injection rates** without **increasing the surface pressure**
Acidizing

- Removing near-borehole drilling mud damage
- Removing carbonates in near-borehole reservoir
- Removing scaling
History

Acidising treatments

- 1895 First acid job
- Successful HCl treatments by the Ohio Oil company
- Corrosion problems
- 1932 HCl with arsenic corrosion inhibitor
- 1933 first HF treatment in sandstone
  - disappointing due to formation plugging – precipitates
- 1940 First HF/HCl treatment
- 1950/60’s Numerous treatments
  - Additives to combat shortcomings
  - Better theoretical understanding
- 1970’s Alternative HF/HCl systems
  - Fluoboric acid
  - Self Generating mud acids, etc
- 1980’s Diversion and placement techniques
  - Foams
  - Coiled tubing
- 1990’s Computerised design and execution support

Acidizing in early days
Acidizing 2000’s
Hydraulic fracturing
IT’S ALL ABOUT IMPROVING THE INFLOW

Optimum connection between reservoir and well
First Hydraulic Fracture Treatment - 1947
Nowadays
Type of Fracturing treatments

- Skin Frac
- Frac & Pack
- Massive Hydraulic Frac
- Multiple vertical fracs
- Multiple horizontal hole fracs
- Acid frac
Objectives for the booklet

- **Identify** methods to enhance and optimize the inflow performance
- **Select candidates** for stimulation treatments
- **Understand** the design and execution of stimulation treatments
Contents

1  Introduction
2  Description of the main types of treatments
3  Differences between geothermal and oil & gas wells
4  Well and Reservoir terms and definitions
5  Work process for selection & design of treatments
6  Preliminary design Matrix treatments in sandstones
7  Preliminary design of matrix treatments in Carbonates
8  Placement/diversion techniques
9  Preliminary treatment design: hydraulic fracturing
10 Completion aspects
11 Other methods – future
12 Operational and environmental aspects
Fracturing treatment design process

Stimulation Treatment Selection existing well

1. Analyze well data: Q, S, W/IQI, etc.
2. If depleted, high water cut, go to "No stimulation candidate".
3. If K<1 mD, go to "Major hydraulic fracturing treatment".
4. If Skin>S, W/IQI>0.9, go to "Slanted or horizontal sidetrack and rework".
5. If Sand problems and Sand control in place, go to "Skin treatment (Frac and Pack)".
6. If Completion fit for frac? yes, go to "Matrix treatment: Low chance for success".
7. If Workover justified and yes, go to "Matrix treatment: High chance for success".
8. If Cause of damage known, go to "Problem well identification".
10. Treatment selection.
11. Treatment design.
12. Treatment result prediction.
13. Operational constraints.
14. Operational stimulation program.
15. Scheduling and logistics.
17. Evaluation cycle.
18. Job execution.
Differences between geothermal and oil & gas wells

- Temperature
- Treatment fluid composition
- Reservoir fluid chemistry
- Flows
- Investment versus gains
- Specific set up with respect to well configuration
Appendices

• Appendix I: causes of formation damage and their cure
• Appendix II: definitions of skin components
• Appendix III: general fluid name cross reference list
• Appendix IV: maximum injection rate for matrix treatments
• Appendix V: Minifrac or Datafrac Procedure
• Appendix VI: layout checklist
• Appendix VII: health safety and environmental aspects
• Appendix VIII: procedures and working plans needed for stimulation activities in NL
Scope of this technical overview

- Technical recommendations
  - matrix stimulation (acidizing)
  - hydraulic fracturing
  - acid fracturing
  - Some other stimulation techniques are described briefly
- Limitations of the guidelines
  - Stimulation of geothermal doublets in permeable reservoirs
  - Written for operators, consultancies and contractors in the geothermal industry
- The technical guidelines in this report are not to be used for:
  - A detailed stimulation treatment design or job execution program
  - Well design, well completion or drilling programs
  - Cost calculations/consideration: prices or costs are not included in these technical guidelines
Scope of this technical overview

- Other techniques
  - There are less commonly used techniques applicable in the geothermal industry. These techniques are described in less detail

- Legal aspects of stimulation
  - Not meant to be guidelines for legislative purposes
  - In most countries the authorities have issued documents dealing with the rules and regulations with respect to well stimulation, specifically fracturing.
  - In the Netherlands SodM (Staatstoezicht op de Mijnen) has recently issued an inventory of fracturing (including acid fracturing) in which the controlling role of SodM is explained.
  - In Germany fraccing permits are arranged by state authorities (Bergamts). The state Lower Saxony has issued several documents specifying the conditions under which fracturing might be allowed.
  - In the UK the DOE (Department of Energy) is the controlling authority.
  - A summary of the Dutch regulations is given
Dank U voor Uw aandacht
Back up slides
FROM SMALL FRAC & PACKS IN HIGH PERMEABILITY SANDSTONES TO massive multi-fracs in Shalegas
Acoustic well stimulation

- Damage removal
  - Fines in near wellbore
  - Drilling Filter-cake
  - (In)organic deposits
- Screen cleaning

Possible configuration
### Candidate Selection Acid Treatments

**requirements as ‘rules’ in spreadsheet**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Requirement Details</th>
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<tr>
<td>Hydrocarbon saturation</td>
<td>30% or more&lt;br&gt;<strong>Highly depleted wells are poor acidizing candidates (from economic point of view).</strong></td>
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<tr>
<td>Water cut</td>
<td>50% or less (can be higher if water can be handled)&lt;br&gt;<strong>Acid will preferentially stimulate water zone</strong></td>
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<td>Gross reservoir height</td>
<td>no limit, but diversion needed in longer wellbores</td>
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<tr>
<td>Permeability</td>
<td>Gas &gt; 1 mD, Oil/water &gt; 10 mD&lt;br&gt;<strong>Low perm reservoirs need a frac, not acid</strong></td>
</tr>
<tr>
<td>Reservoir pressure</td>
<td>Gas: two times the abandonment pressure&lt;br&gt;Oil: 80% depletion</td>
</tr>
<tr>
<td>Production system &amp; tubing</td>
<td>Current production not more than 80% of maximum capacity of facilities&lt;br&gt;<strong>Must be able to handle increased production</strong></td>
</tr>
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Differences between geothermal and oil & gas wells

- **Fracturing in geothermal and shale gas**
  - Frac length for geothermal projects in sedimentary basins 10 to 300m
  - Frac length for shale gas production can be more than 1000m

- **Fluid volumes**
  - matrix treatments of geothermal 50 – 75 m³ of acid or less.
  - fracturing of geothermal wells are normally in the order of 500 m³ or less per fracture.
  - in shale gas and shale oil, 2500 m³ or more per fracture are quite common.

- **Number of fracs**
  - in geothermal doublets the general norm is one or two with a maximum of four per well
  - in shale gas often a large number of fracture treatments per well.

- **Exploitation**
  - shale gas wells have a limited lifetime of a few years. After its lifetime a new well needs to be drilled, including the needed fracturing activities.
  - geothermal wells are meant to produce for 15 to 30 years or even more.

- **Enviromental impact**
  - Staatstoezicht op de Mijnen (legal authority of Economic Affairs in the Netherlands) just published an evaluation on regular oil & gas fracking activities in the Netherlands (252 wells and 338 fracs since 1950). The conclusion is that no harmful effects have occurred.
Doublets, Triplets

SoDM rule does in general not apply for dedicated fracture treatments