Importance of geo-mechanics in the enhancement of permeability for unconventional reservoir

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A SERIES OF OBSERVATIONS ARE PRESENTED TO SHOW THE SIGNIFICANCE OF GEOMECHANICS IN THE DEVELOPMENT OF UNCONVENTIONAL RESERVOIRS. I WILL BE USING ENHANCED GEOTHERMAL SYSTEMS (EGS) AS THE UNCONVENTIONAL RESERVOIR TYPE EXAMPLE.
BASIC EGS CONCEPT

SURFACE POWER PLANT

Microseismic monitoring

Deep wells

Injection well

Production wells

Enhanced natural permeability
Reservoir stimulations

Two major reasons for reservoir stimulations are:

a. To increase permeability of a reservoir (enhance recovery)
b. To reduce near wellbore impedance (kh)
Main mechanisms of reservoir stimulations are:

1. **Hydraulic fracturing**: normally in sedimentary formation including shales. Complex viscous fluid are used in conjunction with proppant to maintain the artificial permeability created. Hydraulic fracturing of the rock mass creates new fractures. The newly created tension fractures are parallel to the maximum stress direction by exceeding the minimum stress and the rock property (tensile strength).

*Mechanism of failure: TENSILE*
Main mechanisms of reservoir stimulations are:

2. **Shear stimulation**: normally in hard rock (igneous) formation but less hard rocks also (e.g., sandstones). Fresh water, brine or the combination of the two is used for stimulation of existing fractures. Injection causes pore pressure in joints/fractures to increase, the joint aperture continues to increase and eventually the joint fails in shear when the normal stress is reduced to zero. This shearing action leaves a permanent residual aperture (permeability) caused by joints asperities. Joints that fail first are the critically aligned joints dictated by the in-situ stress regime & orientation (geo-mechanics).

*Mechanism of failure: SHEAR*
Reservoir Creation Mechanisms

Tensile failure
(less joints)
(Jell/proppant stimulation)

$\sigma_h(\text{min})$

$\sigma_H(\text{max})$

Direction of failure

Seismic signature of a tensile failure
Reservoir Creation Mechanisms

Shear failure
(more joints)
(Fresh water or brine)

Critically aligned joints

\[ \sigma_{h\text{(min)}} \]

\[ \sigma_{H\text{(max)}} \]

Theoretical direction of initial failure
\(~ 22^\circ\) on either side of \( \sigma_{H\text{(max)}} \)

Seismic signature of a shear failure
PREDOMINANT MODE DURING STIMULATION IS SHEAR

Max stress direction

Shearing of joints starts at lower pressure on critically aligned joints but continues to mobilise other joints towards $\sigma_H(\text{max})$ as pressure increases.

Critically aligned joints
Shearing mechanism during a stimulation

1  Fracture aperture before stimulation
2  Fracture aperture during stimulation (seismic event)
3  Increased fracture aperture after stimulation
EGS DEVELOPMENT IN THE UK

at the Rosemanowes site in Cornwall

(1978-2002)
OBSERVED RESERVOIR GROWTH DIRECTIONS

NORMAL FAULTING REGIME
Fracture growth: Horizontal to upward

STRIKE-SLIP FAULTING REGIME
Fracture growth: Horizontal to downwards

Increasing Depth

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Stress profile & Reservoir growth at Rosemanowes

Horizontal to upward growth

Horizontal to downward growth

\( \sigma_{\text{max}} \)

\[ \begin{align*}
A: & \quad \text{VIEW FROM NE} \\
B: & \quad \text{VIEW FROM SE} \\
C: & \quad \text{PLAN VIEW}
\end{align*} \]
WATER LOSS PROBLEM DURING 5 YEARS OF CIRCULATION @ Rosemanowes

Minimum in-situ horizontal stress above hydrostatic at 2 km

FIGURE 9 PRESSURE AGAINST DAILY SEISMIC EVENT RATE AND NET WATER LOSS FROM 5 AUGUST 1985 TO 30 JULY 1987
Location of the European EGS at Soultz, France

Pechelbronn oil field shallow basement

Rhine Graben Tectonics
Overview of wells & seismic monitoring system at The European EGS Project at Soultz, France

Shearing of Fractures principally occurred in the granite
THE OPEN HOLE SECTION OF THE WELL GPK2 (4500-5000m) WAS STIMULATED USING FRESH WATER.

- Flow logs were carried out to see where the flow was leaving the well.
- There were a number of exits from the well but the majority of the flow left at the bottom of the well.
- A microseismic location density map was constructed using 100 m thick depth slices to evaluate shape & direction of growth.
Stimulation of GPK2 & Targetting GPK 3

Depth Range:
4700 m – 4800 m

- 500 m radius circle
- 1000 m radius circle
- Injection point
- Selected position for the second well
Depth Range:

4800 m – 4900 m
Targetting GPK 3

Depth Range:
4900 m – 5000 m
Targetting GPK 3

Depth Range:
5100 m – 5200 m

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Injection test overpressures: 1995 & 2000

>> internal reservoir permeability was strongly enhanced (x20-30)
APPLICATION OF GEO-MECHANICS TO HYDROTHERMAL FIELD NEAR RENO, NEVADA
Plan view of Desert Peak hydrothermal production field

Well 27-15 was not considered based on geology (clay at the depth of interest)

Well 23-1 was the first choice by GeothermEx

SHmax = N27°E from FMS Log Analysis

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Zones with higher drilling penetration rate and some losses.

The flattening temperature gradient indicates convection in this area...
...permeability?
If the stimulation is successful:
Possible use of 27-15 as an injector or a producer.

1) Higher reinjection should enhance production from the field.

2) Once Permeability has been created by stimulation, reinjection can support production from 27-15.
Shear Stimulation Phase (?)

Total pressure at Dp=
Pipe friction losses ($\Delta p_A$) + Interface losses ($\Delta p_B$) + Formation losses ($\Delta p_C$)

$Dp =$ Pressure required to shear a fault

$\Delta p_A$, $\Delta p_B$, $\Delta p_C$

$\sim 4$ to $6$ gpm for $\sim 10$ days @450 psi
No seismic events generated

Rule of thumb:
If you wish to circulate at $X$ l/s
You need to inject at $2X$ l/s.

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High flow rate stimulation

- Constrained by limited pressure with wellhead & casing
- Injection flow was ~550, 735 & 1000 GPM with injection pressure of 1000, 835 & 1200 PSI resulting in an increase in injectivity from 0.012 to 2.1 GPM/PSI, an increase of 175 fold. This was a dramatic improvement in permeability & power output from the plant.
### Important Stimulation Strategies – Well Layout

<table>
<thead>
<tr>
<th>Stimulation of Well 2 aborted too early!</th>
<th>Wells badly positioned!</th>
<th>Proper stimulation &amp; accurate well targets = good connectivity</th>
</tr>
</thead>
</table>

- **Well 1**
- **Well 2**

**σH(max) direction**

**= stimulated zones**
Review of some non commercial wells in (Nevada) for potential improvement.

Field A: 43-33 (1 wells)
Field B: 15-12, 18A-11 (2 wells)
Field C: 27-15, 11-27 (2 wells)
Field D: 14-34, 81-28, 81A-28RD, 46-28 & 33-11 (5 wells)
Field E: 57-8 (1 wells)
Field F: 86-16 (1 wells)

12 wells out of 24 examined could be considered for stimulation. One suspects that similar potential for improvement lies at other hydrothermal fields as well.
POTENTIAL GEOTHERMAL RESERVOIR:

Temperature $T$ & Permeability $k$

Stimulation

$T, k$  $T, k'$

Un economic  economic
WHAT NEXT?

THE MESSAGE:

DURING THE DEVELOPMENT AND IMPROVEMENT OF A RESERVOIR, IT IS IMPORTANT TO CONSIDER THE GEOMECHANIC ASPECTS TO INCREASE THE SUCCESS POTENTIAL. NUMERICAL MODELLING CAN BE DONE TO SCOPE THE STIMULATION.
THE END

THANKS FOR YOUR COOPERATION

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