Optimization of energy valorization on EGS plants

Application to Soultz-sous-Forêts demo-site

Eléonore Dalmais – 18/02/2021
Outline

Introduction
Soultz-sous-Forêts EGS site
Impact of colder reinjection on surface facilities
Impact of colder reinjection on the reservoir
Conclusion and perspectives
Introduction

• Let’s start by a question...

With a fixed well configuration (one doublet for instance), how would you enhance energy production?

• Write your ideas in the chat
Introduction

Thermal power capacity from a geothermal plant

\[ P_{THERM} = \dot{m} \times [c_P]_f \times (T_{PROD} - T_{REINJ}) \]

By stimulating the well

MEET demo-site
Chemical stimulation in
United Down Deep Geothermal Project
(Cornwall, UK)

By extracting more calories
(reinjecting at colder temperature)

MEET demo-site
Colder reinjection
Soultz-sous-forêts (SsF) EGS power plant
(Upper Rhine Graben, France)
Soultz-sous-Forêts demo-site presentation
Upper Rhine Graben

• URG belongs to West-european rift system

• Well known thermal anomalies with thermal gradient up to $100^\circ$C/km

• Development of Enhanced Geothermal Systems technology on the Soultz-sous-Forêts project, deep in the granitic basement (5km depth)

• New plants developed based on this knowledge, targeting shallower depths (fractured sediment / basement interface)
SsF historical background

**Temperature @ 400m depth**
Hass et Hofmann, 1929

- **11 °C/100 m in sediments**

**Geothermal project**
- 1967

**First logging of Schlumberger**
- 1927

**Discovery of hydrothermal spring**
- 1910

**Closing of hydrothermal center**
- 1992

**Bitumen spring exploitation**
- 1498

**Mining exploitation**
- 1735

**Borehole exploitation**
- 1888

**First mention of bitumen spring exploitation**
- 1500
• Initial objective to find 200°C @ 2 km depth and create a reservoir by hydrofrack (hot dry rock)

BUT
• Only 140°C @ 2000m (convection in the deepest sediments and top basement)
• Granite naturally altered and fractured
• Circulation of a natural brine with high salinity

THEN
• The concept switch gradually to the enhancement of initial permeability by stimulating technics (hydraulically and then chemically) -> EGS
Natural brine

Salinity ~100g/L, pH ~ 5.0
Na-Ca-Cl brines, with important concentrations of K
  • Homogeneous in URG

Gas-Liquid Ratio 1 Nm$^3$/m$^3$ mostly CO$_2$

High Li concentration ~170 mg/L

Bosia et al, 2021
SsF development

1987 - 1990
Drilling GPK1 (2,000 m)
Coring EPS1 (2,227 m)

1991 - 1993
Deepening of GPK1 (3,600 m)
Drilling of GPK2 (3,860 m)

1999 - 2007
Deepening of GPK2
Drilling of GPK3/4 (>5,000 m)

2004
Stimulation GPK4

2005
Stimulation GPK4

2006
Chemical Stimulation

2010 - 2012
Power production tests

2015
Power plant refurbishment

Since 2016
Power production

Major failure in power plant
Current situation

3 wells @ 5 km depth (GPK2 – 3 – 4)
- Max temperature: 200°C @ 5 km
- WH Production Temperature: 150°C
- Reinjection temperature: 65 – 70 °C
- Flow rate: 30 kg/s

Power generation with ORC: **1.7 MWe**
Geothermal loop

- Power generation only (SsF)
- Heat generation only (Rittershoffen)
- Combination of heat and power generation (Landau)

Secondary loop
Energy valorization

Separator

Injection pump

Pool

Production pump

Production well

Reinjection well

Prod. filter

Inj. filter
Geothermal loop

Heat exchangers (preheaters and evaporator)

Separators

Production filters

Production well (GPK2) with line shaft pump

Injection wells (GPK3 and GPK4)
Power production

Use of an ORC « Organic Rankine Cycle »
Binary fluid (BF) : isobutane

- 4→5: Preheat and vaporization of BF in the evaporator using geothermal heat
- 5 → 6: BF vapor rotates the turbine, which is directly coupled to the electric generator
- 6 → 7: Exhaust vapor flows through the regenerator, where it heats the organic liquid (2 → 3)
- 7 → 8 → 1: BF is condensed in the condenser and cooled by the cooling circuit
- 1 → 2: BF is then pumped into the regenerator and evaporator
Power production

- Turbine
- Generator
- Pump
- Aerocondensor
- Regenerator
Power production

- Pump
- Turbine
- Generator
- Aerocondensor
- Regenerator
Industrial heat, ECOGI

Providing high temperature heat to the industry, example of Roquette bio-refinery

- Maximizing energy use
  - Operating nearly 24h/d 365d/y
  - No energy loss compared to electricity conversion
- Secure the industrial’s local presence
- Transform local resources (crops) locally

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 wells</td>
<td>2500-3000 m</td>
</tr>
<tr>
<td>Operating</td>
<td>8 000 h/year</td>
</tr>
<tr>
<td>Wellhead Temperature</td>
<td>170°C</td>
</tr>
<tr>
<td>Transport loop</td>
<td>15 km</td>
</tr>
<tr>
<td>Thermal power by the refinery</td>
<td>24 MW</td>
</tr>
</tbody>
</table>
Industrial heat, ECOGI
Electricity and heat

Electricity and heat in serie
Landau (URG)

Electricity and heat in parallel
Unterhaching (Bavaria)
Electricity and heat

Sauerlach (Bavaria)
Challenges in exploitation

Environment
- Noise
- Visual impact
- Natural radioactivity

Reservoir
- Microsismicity
- Thermal breakthrough
- Enhance well production

Technology
- Corrosion & scaling
- Well integrity
- Pumps

Environment

Reservoir
What could be the negative impacts of colder reinjection for the exploitation (surface and reservoir)?

• Write your ideas in the chat
2nd quizz

What could be the negative impacts of colder reinjection for the exploitation (surface and reservoir)?

• Write your ideas in the chat

- Increase scaling issues
- Decrease production temperature
- Increase induced microseismicity
- Thermal impact on casing and cement
Impact of colder reinjection in surface facilities

Scaling issues
Scaling phenomena in SsF

Scale deposition due to change in thermodynamic conditions (pressure, temperature)
- Precipitation of sulfates (barite & celestite)
- Precipitation of sulfides (galena)

Impact on exploitation
- Decrease of thermal exchange efficiency in heat exchangers
- Plugging of equipment
- Incorporation of naturally occurring radioactive material (NORM) ($^{210}\text{Pb}$ and $^{226}\text{Ra}$)

Use of scaling (and corrosion) inhibitors
- No more sulfates
- Increase of sulfides and native metals

By decreasing reinjection temperature from 70°C to 40°C, risk of
- Increase quantity of scale
- Apparition of new scale type (silica)
Small heat exchanger test - design

On site test of brine cooling
- Temperature cooling down to 40°C in 3 passes
- Flow rate Q= 4.1 kg/s for brine (10% of Soultz nominal flow rate) and 21.3 kg/s for cooling water
- Duration 3 months: February – April 2019

Design of the test heat exchanger
- 6 metallurgies selected for HEX tubes
  - 1.4539 : Austenitic stainless steel with molybdenum (904L)
  - 1.4547 : Highly alloyed austenitic stainless steel (254 SMO)
  - 1.4462 : duplex (austenitic-ferritic) stainless steel (2205)
  - 1.4410 : super duplex stainless steel (2507)
  - 3.7035 : pure titanium (Ti grade 2)
  - 2.4858 : High nickel alloy (Alloy 825)

Ravier et al, 2019
Ledesert et al, 2020
Small heat exchanger test - run

Measured temperature along the test

• Brine average inlet temperature: 64.2°C
• Brine average outlet temperature: 40.8°C
• Temperatures in line with calculation
• Heat coefficient transfer: 27% of decrease

➢ Indication of scale formation

Ravier et al, 2019
Small heat exchanger test - dismantling

Observation of quantity and adhesion of scaling in the HEX pipes

<table>
<thead>
<tr>
<th>Tube material</th>
<th>64.2°C ± 3.6°C</th>
<th>47.5°C ± 3.8°C</th>
<th>40.8°C ± 4.2°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>904 L</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>254 SMO</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>DX 2205</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>SDX 2507</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Alloy 825</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Ti Gr.2</td>
<td>1</td>
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Rating of quantity of scaling (1 : low , 3 : high)

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<tr>
<td>Ti Gr.2</td>
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<td>3</td>
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</table>

Rating of adhesion of scaling (1 : easy to clean , 3 : hard to clean)

First qualitative results:

- Ti Gr 2 and Alloy 825 (Ni) are not recommended
- SDX 2507 (currently used) is fine until at least 47.5°C
- 254 SMO is an interesting option for new project

Ravier et al, 2019
Scales analysis

Analytical methodology
- In-situ characterization
- Global characterization
  - SHEX tubes
  - Tube cleaning
    - High pressure
    - and/or blasting
  - Scales sampling
- Mineral characterization
  - SEM
  - ICP-MS
  - XRF
- XRD

Mineralogy & chemistry
- Mostly Galena \((\text{PbS})\) enriched in As and Sb (sometimes also Cu) + Halite \((\text{NaCl})\)
- very little Si (no bearing mineral identified)

Radioactivity
- Only \(^{210}\text{Pb}\) and daughter element \(^{210}\text{Po}\)

Chemical composition (XRF) of the scales

X-ray diffraction spectra

Ledesert et al, 2020
Scales analysis

Variation between metallurgies
- No observable difference in scales
- Elemental variation like Al oxides, Ti oxides, free metal particles are likely due to pollution of scales during sawing
- Only a difference of adhesion to the pipe when sampling

Evolution with temperature
- Pb decreases from 60°C to 50°C while Sb and As increase
- Scales tend to be thicker when T decreases

Chemical variations of Pb, S, Sb, As (ICP-MS) depending on temperature

Evolution of major elements in the scales formed from 150°C to 40°C. 2018 data is issued from exploitation scale analysis; 2019 data correspond to MEET SHEX results

Ledesert et al, 2020
Scales analysis - conclusion

No important change for scaling behaviour when decreasing reinjection temperature from 70 down to 40°C

- Same mineralogy
- Thickness slightly higher but acceptable

2 metallurgies are not recommended due to scaling adhesion (difficulties for cleaning in plant operation)

- 3.7035 : pure titanium (Ti grade 2)
- 2.4858 : High nickel alloy (Alloy 825)

Next step: test of decreasing reinjection temperature at full flow rate with mobile ORC to valorize the extra heat into electricity

- 40kWe to be produced
- Test will start soon
- Duration: 4 months

See talk of A. C. Mintsa (19/02/2021)
Impact of colder reinjection on the reservoir

Production temperature
Challenge in modeling fractured reservoir

In reservoirs such as SsF one, flow is channeled through altered and fractured rocks.

Due to natural complexity of reservoirs and numerical limitation, models are always a simplification of reality.

Depending on the question to answer, different approaches for modeling can be undertaken:

• For temperature decrease at production, modeling may focus on a small number of deterministic features connecting the wells.
• For microseismicity assessment, smaller fractures needs also to be taken into account. A stochastic approach will then be more appropriate.
From data to structural model

- 3rd quizz

Thousands of fractures recorded in granite on SsF wells, but a few of them are permeable.

Which data should be acquired to determine what zones are contributing to the well flow and what discrete features should be included in a structural model?

Desayes et al, 2010
From data to structural model

**Drilling**
- Mud losses -> permeable zones (qualitative)
- Gas influx -> permeable zones (qualitative)

**Logging**
- Cores / images logs -> orientation, aperture of fractures
- Temperature logs -> permeable zones (qualitative)
- Flow logs -> permeable zones (quantitative)

**Seismic information**
- 2D/3D sismic surveys -> fault at sediment – basement interface
- Vertical seismic profiles -> intra-basement near well faults
- Microseismic monitoring -> fluid pathways
Permeable fractures from well data interpretation

Example in GPK-1
Intra basement faults from seismic information

GPK2 structural interpretation from microseismic data (Sausse et al, 2010)

GPK1 structural interpretation from VSP data (Place, 2007)

Full Wave Inversion of OVSP data
Proof of concept on synthetic data (Abdelfettah et al, 2020)
SsF structural model

Derived from
- Well logging data
- Microseismic events analysis
- VSP analysis

Integration of information derived from 2D seismic
- Main sedimentary layers
- Faults in sediments

Short selection of intra-basement faults
- based on permeability indicators

Rolin, 2019
From structural to dynamic model

Further simplification

- 5 faults are kept
- Representative of major flowing zones and well connections
- Connection of a fault to the boundary -> far field contribution

Rolin, 2019
Hydrothermal modelling

Boundary and initial conditions

Constant Hydraulic Head condition on N,E,S,W borders

Surface temperature: 10°C
Bottom heat flux: 72 mW/m²

Initial temperature based on well temperature log (extrapolated to the bottom of the model at 8 km)
Granite radiogenic heat production: 3.10⁶ W/m³

Calibration on production data

1- Hydraulic calibration (steady state): fixed flow rate, matching of well head pressure and contribution of each well section
2 – Thermal calibration (transient state): fixed flow rates and injection temperature, matching of production temperature

<table>
<thead>
<tr>
<th>Name</th>
<th>Hydraulic Conductivity [m/s]</th>
<th>Specific Storage [1/m]</th>
<th>Porosity</th>
<th>Thermal Conductivity [W/m/K]</th>
<th>Heat Capacity [J/m³/K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granite</td>
<td>7 10⁻⁹</td>
<td>1.75 10⁻⁸</td>
<td>3%</td>
<td>2.5</td>
<td>2.9 10⁶</td>
</tr>
<tr>
<td>Faults</td>
<td>between 10⁻⁶ &amp; 10⁻⁴</td>
<td>2 10⁻⁶</td>
<td>10%</td>
<td>2.5</td>
<td>2.9 10⁶</td>
</tr>
</tbody>
</table>

Except for FZ4760, parameters initially based on Gentier, 2010; Jung, 2013 ; Held, 2014 ; Sausse et al., 2010 and fine tuned
Hydrothermal modelling - conclusion

Results

- Around 5°C difference between reinjecting @ 40°C and current reinjection temperature (~65°C)
- Rapid decrease and then stable behaviour -> highlights short connection and more far field contribution

Rolin, 2019
Impact on the reservoir & the environment

Microseismic activity

Increase monitoring
- Additionnal sensors
- Innovative monitoring with optic fibre

Thermo-hydro-mechanical modelling
- Assessment of reservoir geomechanical behaviour (increase of microseismicity due to colder reinjection?)

See talk of V. Lanticq (19/02/2021)

See talk of S. Mahmoodpour (18/02/2021)
Conclusion and perspective

At this stage of MEET project, colder reinjection (down to 40°C) seems feasible

- No major impact on scaling issues
- Acceptable impact in production temperature

At the URG scale, this could provide additionally +33MWth

How to valorize this additionnal MWth ?

- Electricity generation (mobile ORC test)
- Direct heat use

![Graph showing current and additional thermal power]
Thank you very much for your attention

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