Webinar EGEC Market Report 2021

Innovation in geothermal drilling:

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EGEC President
Outline

• Innovative well architectures – highlights
  • Subhorizontal (SHW) well architectures
  • Multiradial (MRW) well architectures
  • Anti-corrosion well concept
  • Dual-completions

• Conclusions
  • Well Performance
  • Key issues in reservoir petrophysics evaluation
TECHNOLOGY: SUMMARY OF WELL ARCHITECTURES

- Conventional deviated (DEV)
- Drains subhorizontal
- Drains rayonnants

Profil du puits producteur

Production

Injection

EGEC GEOThermal
The Dogger (Bathonian member) target reservoir is hosted by the Upper part of the carbonate platform. Within the platform oolitic limestone sequences exhibit high connected porosities and related permeabilities portraying a dependable multilayered reservoir structure.
SHW DOUBLET ARCHITECTURE AND OFFSET WELL TRAJECTORIES

A) WELL ARCHITECTURES

B) WELL TRAJECTORIES

C) SHW AND CANDIDATURE OFFSET WELL TRAJECTORIES
SHW GEOSTEERING WORKFLOW

WELL GCAH1

Planning Phase
GCAH-1
Geological Pre-drilled model
Well Plan
Log responses model

Monitoring
Directional
LWD
XRF/XRD
MUD Logging

1

Decision
Geosteering
TD?

Analysis
- Production logging tool
- Test

Post-Drill

Real Time

GCAH1 DATA
XRF/XRD
Production tool
LWD
Mud Logging

WELL GCAH2

Planning Phase
GCAH-2
Geological Pre-drilled model
Well Plan
Log responses model

Monitoring
Directional
LWD
XRF/XRD
MUD Logging

1

Decision
Geosteering
TD?

Analysis
- Wireline Nuclear Magnetic Resonance and Sonic Dipole
- Test

Post-Drill

Real Time
**GEOSTEERING**

**REAL TIME Trajectory CORRECTIONS**

- **Challenge: Real time trajectory corrections**
  - 1 to 5° varying dips, impacting drain effective length
  - Reconcile tracking of thin (#1 m) high porosity layers with target matching delays induced by high bit to RSS recording distance (#20 m)
SHW PETROPHYSICAL DATA EVALUATION WORKFLOW

<table>
<thead>
<tr>
<th>Drilling &amp; Geosteering</th>
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<tbody>
<tr>
<td>Cuttings analysis</td>
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<tr>
<th>Wireline Logging tractor conveyed</th>
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<tr>
<td>Dipole Sonic</td>
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<tr>
<td>NMR Magnetic Resonance</td>
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Data analysis → Inputs to development

Rock quality and productive segments characterization Porosity and permeability; rock heterogeneity

(SOURCE: ERIK WIELEMAKER ET AL, 2020)
MULTIRADIAL WELL (MRW) ARCHITECTURE

Three, inclined 80°, radial drain well trajectories

Impacts of drain architecture on well performance

<table>
<thead>
<tr>
<th>WELL ARCHITECTURE</th>
<th>CUMULATED DRAIN LENGTH (m)</th>
<th>MAXIMUM PRESSURE DEPLETION @400 m³/hr (bar)</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Single (45° incl.) drain</td>
<td>15</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>Multiradial Three (1x45° + 2x70° incl.) drains</td>
<td>190</td>
<td>37</td>
<td>High drain Interference Impact</td>
</tr>
<tr>
<td>Multiradial Three (1x45° + 2x80° incl.) drains</td>
<td>240</td>
<td>25</td>
<td>Limited drain Interference Impact</td>
</tr>
</tbody>
</table>
MRW VS CONVENTIONAL WELL ARCHITECTURE PERFORMANCE

Conventional (single, inclined 45°, leg) well architecture

Innovative (three, inclined 80°, radial drain) well architecture
INNOVATION: ANTICORROSION WELL CONCEPT

Present well architecture addresses an artificial lift, pump sustained, production, which implied significant design modifications, chiefly:

(i) an upper, wider (13"3/8OD - 11.97" ID) liner section acting as a pumping chamber, sized to accommodate a 500 HP rated ESP, placed under compression between the wellhead and the lower section;

(ii) a lower and slimmer (9"5/8OD – 7.74" ID), freely suspended production liner;

(iii) a (13"3/8x9"5/8) liner connecting system, placed at the (20"x13"3/8) casing interface, allowing for a free annular fluid (a make-up corrosion inhibitor agent) passage, indeed a key issue, and,

(iv) a wellhead expansion spool. The additional capital investment costs (ca 20% compared to a conventional 13"3/8x9"5/8steel cased well architecture) will get payed back in less than eight years thanks to yearly OM costs savings.

Given the foregoing, it is expected this, smart well, material answer to thermochemically hostile corrosive fluid environments, elsewhere securing well longevities and low operation/maintenance (OM) costs, raises due interest among geothermal operators and stakeholders.
DUAL WELL COMPLETION

**KEY**:
- C: Casing
- D: Drilling
- DV (IS): Stage Cementing Collar (innerstring)
- LH: Liner Hanger
- SP: Sealing Plug
- UR: Undreaming
- WRS: Wirewrapped screen

**AQUIFER A**

**KEY**:
- A: Albian
- BPA: Boost Pump Albian
- CF: Cartridge Filter
- ESPN: Electrosubmersible Pump Neocomian
- GHEA: Geothermal Heat Exchanger Albian
- GHEN: Geothermal Heat Exchanger Neocomian
- IPA: Injection Pump Albian
- IPN: Injection Pump Neocomian
- N: Neocomian
- P/Q/T: Pressure/Flowrate/Temperature

**Geothermal loop**

**Heating grid**
Well profile designed to accommodate a deepening from bottom reservoir A to top of reservoir B via an Expandable Liner (EL) and a dual miscible reservoir production thanks to wire wrapped screens (reservoir B) and EL perforations (reservoir A)
DUAL GEOTHERMAL ESP COMPLETION

DUAL PARALLEL ESP(*)

DUAL CONCENTRIC ESP(*)

WELL CASING PROFILE

(*) SOURCE: SCHLUMBERGER, 2020
CONCLUSIONS. KEY ISSUES

1. WELL PERFORMANCE

Exemplified by the following records.

- **SHW Architecture. Operating GCAH doublet**

<table>
<thead>
<tr>
<th>STATUS</th>
<th>DOUBLETS</th>
<th>FLOW &amp; ENERGY RATINGS</th>
<th>COP</th>
<th>MINING CAPEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Previous</td>
<td>2</td>
<td>350 m³/hr; 40 GWh₂th/yr</td>
<td>9</td>
<td>14-15 Mio €</td>
</tr>
<tr>
<td>Present</td>
<td>1</td>
<td>450-500 m³/hr; 60-65 GWh₂th/yr</td>
<td>20-28</td>
<td>12-13 Mio €</td>
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- **MRW Architecture Design**

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- **Combined steel Fiberglass, Free anulus, Well Architecture. Two operating wells**

Secures well integrity (corrosion free, longevity, minimum well losses)

- **Dual Completion Design**

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<tr>
<th>RESERVOIRS</th>
<th>TEMPERATURES (°C)</th>
<th>DISCHARGE RATES (m³/h)</th>
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<tr>
<td>A</td>
<td>64</td>
<td>250</td>
</tr>
<tr>
<td>B</td>
<td>75</td>
<td>150</td>
</tr>
<tr>
<td>A + B</td>
<td>68</td>
<td>400</td>
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CONCLUSIONS. KEY ISSUES

2. INSIGHT INTO RESERVOIR PETROPHYSICS

SHW implementation, to be fully rewarding, requires a Multiphysics approach to reliably assess layer continuity and heterogeneity, achieved by.

- **Logging**
  - **LWD**
    Azimuthal density & multifrequency resistivity assistance/guidance to Geosteering
  - **OH Wireline. Tractor driven**
    NMR (CMR) provides porosity, permeability and connectivity information
    SONIC DIPOLE provides Geomechanical parameter along imaging layer lateral extent

- **Geochemical XRF, XRD**
  - Identifies diagenetic, cement, microfracturing attributes driving porosity trends
  - Geochemically traced lateral carbonate variations help, with LWD, optimizing the geosteering process

The foregoing are becoming a standard reservoir assessment package, likely to be complemented by VSP processing.
THANK YOU FOR YOUR ATTENTION

Geothermal Energy: renewable-sustainable-proven-achievable-realistic

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