Full Scale Field Testing of Sealant Materials for CO2 Leakage Remediation

- Bečej CO2 Field, Serbia -

9th "Trondheim Conference on CO2 Capture, Transport and Storage"

Jafar Abdollahi and Inge Manfred Carlsen (PRORES), Jens Wollenweber (TNO), Bernd Wiese (GFZ), Marc Fleury (IFPEN), Ivan Basic, Aleksandar Patrnogić and Dusan Karas (NIS).
Content

- Introduction
- Field test objectives
- Sealant solution
- Well operations
- Results
- Conclusions
The main objective of the MiReCOL is to develop corrective measures for CO$_2$ leakages through formations and along wells.

The purpose of test is to demonstrate a practical approach for transforming laboratory scale solutions to a full field scale use.

NIS as one of the largest energy companies in Europe operates a natural CO$_2$ field in Serbia.

The Bečej 002 well was made available for testing of a near wellbore formation sealant.

The project partners performed field and materials studies and well planning.

NIS was responsible for all field logistics, well preparations and operations.

The experience from this field test is unique.
One of the largest natural CO₂ fields in Europe, discovered in 1951

- **Major blow-out** in 1968, lasting 8 months with collapse of the lower section of the well (Bečej-5)

- From 1968 to 2001 the reservoir pressure dropped from 150 to 117 bar due to an underground gas migration at shallow depth around 650 mMD. This was confirmed by pressure and chemical analysis during drilling of well Bečej-2 in 2002.

- In 2002, the Bečej-002 well was drilled but temporarily abandoned at the reservoir level.

- **Successful remediation** in 2007 with use of two relief / kill wells (*remediation and observation wells*). 1700 m³ of different chemical solutions was pumped (water glass, polymer, activators, cross linking agents and acid).
Field Test Objectives

- Test a sealant material in a formation containing CO2, to clog the porous media near the wellbore as a permanent long term barrier,
- Provide valuable reference data on the feasibility of shutting off well-formation communication using this type of material.

<table>
<thead>
<tr>
<th>Goal</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up-scaling and mixing fluid in the field</td>
<td>Homogenous fluid, low viscosity, no flocculation</td>
</tr>
<tr>
<td>Avoiding gelation inside the well</td>
<td>Obtaining normal well circulation</td>
</tr>
<tr>
<td>Placing the seal in the formation</td>
<td>Correct fluid displacement</td>
</tr>
<tr>
<td>Clogging the new wellbore formation</td>
<td>No hydraulic contact between well and reservoir</td>
</tr>
<tr>
<td>Long term sealing performance</td>
<td>No influx in well during monitoring</td>
</tr>
</tbody>
</table>
Geology of Well Bečej 002

Perforated interval

CO₂ test layer interval, 650 - 663.5 m
## Formation Properties of the Chosen Interval

**Petrophysical interpretation of well logging data from 2002.**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Gross</th>
<th>Net</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interval (m)</td>
<td>659,2 - 671,5</td>
<td></td>
</tr>
<tr>
<td>Thickness (m)</td>
<td>12,3</td>
<td>10,2</td>
</tr>
<tr>
<td>Vsh (ppu)</td>
<td>0,21</td>
<td>0,19</td>
</tr>
<tr>
<td>Φtot (%)</td>
<td>36,20</td>
<td>36,10</td>
</tr>
<tr>
<td>Φeff (%)</td>
<td>26,60</td>
<td>27,20</td>
</tr>
<tr>
<td>K (mD)</td>
<td>89,93</td>
<td>87,80</td>
</tr>
<tr>
<td>SW(%)</td>
<td></td>
<td>29,30</td>
</tr>
</tbody>
</table>

**Results of DST from 2002.**

<table>
<thead>
<tr>
<th>DST (min)</th>
<th>Result</th>
<th>IDP (bar)</th>
<th>FDP (bar)</th>
<th>FSP (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>95</td>
<td>CO2</td>
<td>69,4</td>
<td>66,5</td>
<td>84,1</td>
</tr>
</tbody>
</table>

**Formation fluid (%)**

CO₂: 51.33 % and CH₄: 44.41 %

**The lab tests done on cores from identical formation on well Bčj-1**

<table>
<thead>
<tr>
<th>Litology</th>
<th>Porosity (ppu)</th>
<th>kv (mD)</th>
<th>kh (mD)</th>
<th>Total carbonates (ppu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandstone, fine-to coarse-grained</td>
<td>0,33</td>
<td>83,34-720,11</td>
<td>0,78-453,27</td>
<td>0,16-0,50</td>
</tr>
</tbody>
</table>

| | | 370 | 307,50 | 0,35 |
Why a potassium silicate solution?
- Low viscosity, high molar ratio
- Potassium silicates may have a slower kinetics

Why using acetic acid?
- Reactivity with CO₂ is much too fast
- Must generate small pH variation to tune the gelling kinetics
- Empirical choice of a weak acid at a low concentration (like vinegar)

Why diluting the Betol K28T
- To lower further the viscosity

How were the gelling times measured?
- Visual observations (screening)
- Rheology
- NMR relaxation

Gelling time
- Effect of temperature
- Effect of acid fraction
- Effect of salt

Identical project in Australia
(Prof. R. Haese, University of Melbourne, PhD and post-doc program, met at GHGT13, Lausanne)
Mixing of the sealant at the surface is critical

- Going from the laboratory scale to the field application needs careful engineering
- Had to use extra sealant for testing in the mixing tank
- This led to pumping of less sealant volume than originally planned (2 m$^3$ instead of 8 m$^3$)
Well Bečej 002 Before Test

Well data and status

- **Good well integrity, almost fresh well, drilled 2002**
- **No completion string installed, good candidate for testing**
- **5’’ liner was installed at total depth (1145.5 mMD) and cemented**
- **Existing fluid inside well; mud with 1.16 SG**
- **Available DST test data from construction period (2002)**
  - Confirming presence of CO₂ at shallow sand formation
  - Pore pressure data and temperature
  - Formation fracture gradient
- **Wellhead and X-mas tree were installed**
- **Test objective: reduce productivity of the near wellbore formation (~1 m radially)**

Field test goal:
- Invasion radius: ~1 m
- \( K \rightarrow 0 \)
Well Preparations Before Injecting Sealant

Operational sequence

- Mobilization and rig up of workover rig
- Disconnected X-mas tree and install BOP
- Performed drift diameter check
- Displaced well volume with saline water / brine (1.39 sg)
- Installed cement plug (873 – 775.54 m)
- Performed casing integrity log
- Set a bridge plug at 668 m
- Perforated 3.5 m CO₂ test layer interval
- Set retrievable packer at 650 m (10 m above perforation)
- Performed injectivity test with 5 m³ ammonium
Operational sequence

- Pumped spacer (technical water)
  - V = 8 m³, Q = 290 – 300 lpm, P = 22 bar
- Mixed sealant solution (water, Betol, acid) and squeezed
  - V = 2.1 m³, Q = 150 lpm, P = 7 bar
- Displaced sealant solution with technical water
  - V = 2.07 m³, Q = 110 – 120 lpm, P = 0 - 17 bar.
- Well closed for 24 hours and both tubing and casing pressures reported to zero

Animation

Sealant Injection

- 5'' @ 1145.5 mMD
- 7'' @ 925.3 mMD
- 9-5/8'' @ 379.3 mMD
- 13-3/8'' @ 21 mMD

Top sealant: 658 m
Perforation: 660 – 663.5 m

Formation fluid (Gas), ~ 0.3 sg
Ammonium chloride, 1.01 sg
Saline water, 1.39 sg
Technical water, 1 sg.
Sealant solution, 1.1 sg.
Killed well
Pressure monitored: zero (0)
Surface tubing pressure = 14 bar
Surface tubing / casing pressure = 0
Decided to perform P&A
Packer set
Displaced spacer
No mud loss observation
Well opened at 07:00 AM
The well opened at 09:00 AM
Well static
Possible for reverse circulation
Squeezed sealant
At 12:00, well was opened with gain 500 l
Gained 300 l water
Performed reverse circulation
Trip in, tag an obstruction at 660 m
Well on loss & gain
Displacement completed at 09:00 (?)
Well closed, tubing pressure was risen to 15 bar
Injected 200 l
Lost: 1.1 m³, no gas observed
Installed two cement plug at two different depths
Killed well via annulus, well monitored
Pressure monitored: zero (0)
Injected 300 l water through tubing
Performed reverse circulation
Injectivity test, 245 lpm @ 20 bar
Pressure test on plugs
25 - Thu
26 - Fri
27 - Sat
28 - Sun
29 - Mon
30 - 31 - Tue - Wed
Well preparation
Sealant injection
Well monitoring
Well plugging
Lost circulation
Well stable
Well gain (kick)
Injection to formation
P&A operation
Pore pressure 84 bar as measured in 2002 and is not corresponding to injection pressure
Lower injectivity after sealant injection shows permeability impairment.
Well abandonment operation

- Set first cement plug 658 – 616 m
- Set second cement plug at 100 – 58 m
- Lay down BOP and install X-mas tree
- Rig release
- Pressure monitoring

Animation
### Observations

<table>
<thead>
<tr>
<th>Goal</th>
<th>Criterion</th>
<th>Success</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upscaling and mixing fluid in the field</td>
<td>Homogenous fluid, low viscosity, no flocculation</td>
<td>yes</td>
</tr>
<tr>
<td>Avoid gelation in open borehole</td>
<td>Normal well circulation possible,</td>
<td>yes</td>
</tr>
<tr>
<td>Place seal in formation</td>
<td>Correct displacement</td>
<td>yes</td>
</tr>
<tr>
<td>Seal formation</td>
<td>No hydraulic contact between well and reservoir</td>
<td>yes</td>
</tr>
<tr>
<td>Longterm sealing performance</td>
<td>No influx in well during monitoring</td>
<td>Yes, for the time of monitoring</td>
</tr>
</tbody>
</table>

- NIS offered an excellent full scale field test environment with logistics and operational expertise
- The co-operative efforts of the team at the well site were excellent and with a problem solving attitude
Lessons Learned and Conclusions

Major findings:
• The Bečej-002 well was an excellent candidate for this type of test
  - Reservoir access
  - Injectivity
  - The presence of CO2 was confirmed
• Well was not static with loss and gain (good reservoir conductivity)
• All mobilized equipment were fit-for-purpose (rig, pumping, well control, fluids, etc)
• After sealant treatment a pressure build-up was observed after two days
  - This is most probably due to the reduced volume of sealant
  - Elongated sealant reaction time in the field due to cooling of formation by repeated injection (42 C to ~ 22 C)

Lessons learned:
• Perforation interval is critical and need to be optimized
• Preferable use of material with a faster gelation time
• The importance of operational contingency (materials, etc.)
• Increase margins (dead volumes in well and tanks, etc.)

Conclusions:
• The Becej field test was an important step stone towards understanding of CO2 formation leakage treatment
• Going from a theoretical / laboratory scale to full scale field operations is a big step involving many operational issues
• The test criteria for sealant selection is critical before going to the field
Research in this paper was conducted with funding from the European Commission FP7 project MiReCOI (www.mirecol-co2.eu), Grant Agreement n° 608608.

The project received additional funding from Statoil, ENGIE and Shell.