Pipe Materials in Reykjanes Geothermal Environment

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Reykjanes Geothermal Environment
Content

- Schematic Diagram of the Power Plant
- Chemistry of Fluids Changes along the Process
- Pipe Materials
- Various Damages
- Mitigations
- IDDP 2
Reykjanes Power Plant Pipe Materials

- **Supply pipes**
  - Wellhead
  - Carbon steel St37.0, ERW pipe
  - St. 35.8 seamless
  - Steam wells
  - Two-phase wells

- **Knock out separator**
  - P355NH
  - St. 37.0
  - 18 bar

- **Main steam pipeline, SAW**
  - St. 35.8 seamless
  - ERW pipe
  - 1,2 km

- **Steam went stack**
  - 82 kg/s
  - 1.2 km
  - 19 bar

- **Moisture separator**
  - Outlet header
  - 18 bar

- **Turbine inlet pipe**
  - 8)

- **Condenser**
  - Steam pipe to ejectors
  - 9)

- **Cooling seawater GRP**
  - 1600 l/s

- **Mixing wessel**
  - 316 ss

- **Brine/condensate mixture**
  - 60 kg/s
  - 160°C

- **Concrete culvert**
  - ERW pipe
  - 1900 l/s

- **Condensate**
  - 316 ss
  - 80 l/s

- **P 235 GH**
  - ERW pipe

- **Brine/condensate mixture**
  - 60 kg/s

- **Atlantic Ocean**

- **Pipe materials**

- **Enthalpy**
  - 1400 kJ/kg

- **Temperature**
  - 210°C

- **Flow rates**
  - 226 kg/s
  - 314 kg/s
  - 82 kg/s
  - 72 kg/s

- **Reinjection well**
  - Atlantic Ocean
Wellhead chemistry

<table>
<thead>
<tr>
<th>Liquid phase (ppm)</th>
<th>Steam phase (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>pH (°C)</strong></td>
<td>5.02 / 21.3</td>
</tr>
<tr>
<td>CO₂</td>
<td>66.2</td>
</tr>
<tr>
<td>H₂S</td>
<td>1.38</td>
</tr>
<tr>
<td>NH₃</td>
<td>1.93</td>
</tr>
<tr>
<td>B</td>
<td>9.33</td>
</tr>
<tr>
<td>SiO₂</td>
<td>923</td>
</tr>
<tr>
<td>Na</td>
<td>12020</td>
</tr>
<tr>
<td>K</td>
<td>1780</td>
</tr>
<tr>
<td>Mg</td>
<td>1.25</td>
</tr>
<tr>
<td>Ca</td>
<td>1910</td>
</tr>
<tr>
<td>F</td>
<td>0.25</td>
</tr>
<tr>
<td>Cl</td>
<td>23740</td>
</tr>
<tr>
<td>Br</td>
<td>85.2</td>
</tr>
<tr>
<td>SO₄</td>
<td>14.0</td>
</tr>
<tr>
<td>Al</td>
<td>0.0770</td>
</tr>
<tr>
<td>As</td>
<td>0.142</td>
</tr>
<tr>
<td>Ba</td>
<td>13.1</td>
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</tbody>
</table>

Pipe materials
SSC regions from NACE MR0175

Y: in situ pH

X: H₂S partial pressure, expressed in kilopascals

0,3 kPa (0,05 psi)

Pipe materials
A Crack in a 28” SAW Steel Pipe after 10 yrs of operation
A Repaired Crack
Reykjanes Power Plant – Crack History

- Plant commissioned in May 2006
- First pipes started leaking in January 2007
- Cracks form, most often, in HAZ of welds
- First pipes to leak have high Mn %
- Seamless pipes do not crack
- Hot-formed fittings do not crack
## Time Until First Crack.

<table>
<thead>
<tr>
<th>Location number</th>
<th>Location</th>
<th>Time until first crack</th>
<th>Mn %</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Moisture Separator Outlet</td>
<td>8</td>
<td>1,16</td>
</tr>
<tr>
<td>7</td>
<td>Moisture Separator Outlet</td>
<td>9</td>
<td>1,12</td>
</tr>
<tr>
<td>4</td>
<td>Separator Manhole</td>
<td>11</td>
<td>1,16</td>
</tr>
<tr>
<td>4</td>
<td>Separator Inlet</td>
<td>12</td>
<td>1,12</td>
</tr>
<tr>
<td>9</td>
<td>Ejector Motive Steam Pipe</td>
<td>12</td>
<td>0,52</td>
</tr>
<tr>
<td>8</td>
<td>Turbine Inlet Pipes</td>
<td>24</td>
<td>0,55</td>
</tr>
<tr>
<td>6</td>
<td>Main Steam Pipeline</td>
<td>72</td>
<td>0,55</td>
</tr>
</tbody>
</table>
A Pipe Connection to a Tee on Top of a Moisture Separator

<table>
<thead>
<tr>
<th>Pipe</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>N</th>
<th>Al</th>
<th>Cu</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>ø711 x 12</td>
<td>0.117</td>
<td>0.20</td>
<td>1.12</td>
<td>0.013</td>
<td>0.0020</td>
<td>0.0039</td>
<td>0.033</td>
<td>0.180</td>
<td>0.040</td>
<td>0.170</td>
<td>0.01</td>
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<tr>
<td>ø610 x 12</td>
<td>0.124</td>
<td>0.16</td>
<td>1.16</td>
<td>0.011</td>
<td>0.0021</td>
<td>0.0023</td>
<td>0.032</td>
<td>0.134</td>
<td>0.032</td>
<td>0.155</td>
<td>0.01</td>
</tr>
</tbody>
</table>
Hardness Test

The steel here is considerably softer than the prescribed NACE MR173 limit of 22RC for steel in sour environment.
Cracks in the Moisture Separator Nossles

In 2016, welds were clad with Duplex 2205. Therefore, short experience. Exciting!
Corroded Mist Eliminator Pad, 316 stainless

2205 Duplex after 5yrs in service
Turbine Scaling, FeS$_2$ and MnS
## Pipe Material in Reykjaness Power Plant

<table>
<thead>
<tr>
<th>Materials</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seamless Carbon Steel Pipes</td>
<td>Steam Lines, Wellheads</td>
</tr>
<tr>
<td>Welded Carbon Steel Pipes</td>
<td>Brine, Two Phase Flow, Old Steam Pipes, Reinjection Pipes.</td>
</tr>
<tr>
<td>Titanium</td>
<td>Oil and Generator Coolers, Seawater Condenser Tubes</td>
</tr>
<tr>
<td>Type 316 Stainless Steel</td>
<td>Condensate Pipes, Condenser Shell</td>
</tr>
<tr>
<td>Duplex Stainless Steel 2205</td>
<td>Gland Steam Ejector Exhaust Pipes, Mist Eliminator Pads</td>
</tr>
</tbody>
</table>
Blowout!

Pipe materials
Scaling

- Scaling
- Metal Sulfides
- Silica
IDDP 2: Deeper Drilling

Pipe materials
Wellhead Valve, Expanding Gate Valve

IDDP 2 improvements from IDDP 1
Inconel 725 valve stem
Stellited gate segments
Clearances allow for thermal expansion
Wellhead and Casing Expansion Spool

IDDP 2 improvements from IDDP 1

Top of 7" sacrificial casing: Alloy G3

Expansion spool: Inconel 625 cladding.

Internals: Inconel 718
Thank you for your attention
Questions?