PE-X Borehole Heat Exchangers
for high temperature UTES applications
Okotoks borehole thermal energy storage system (BTES)

• 52 family homes
• 2300 m² solar thermal collectors for space heating
• Solar heat collected in summer is stored for use in winter.
• high temperatures up to 90 °C (~200 °F) allows to store these large quantities of solar heat underground in soil and rock.
• Domestic hot water is supplied by individual small solar water heating systems in each house.
Project team

Storage concept:
  IFTech International, Netherlands
  ZAE Bayern, Germany
On-site planning and supervision:
  Enermodal Engineering Limited, Canada,
BHE supplier:
  REHAU
Support:
  Canadian government

Storage design

144 single -U borehole heat exchangers,
Length: 35m each

Two 120m³ hit water buffer tanks:
UTES design

- $\frac{3}{8}''$ PE-X BHE
  - 6 in series

- 6 lines in parallel
  - 6 in series

- supply

- return

- energy centre
Requirements for BHE’s for thermal storage:

• Resistance against internal pressure at elevated temperatures

• Resistance against external action

• Minimized joint failure probability
Resistance against internal pressure at elevated temperatures

Standard situations:
• Temperature levels / maximum operating temperatures are determined by the boiler settings
Solar thermal heat supply:
• Temperature levels are determined by the weather situation and the storage temperature

- typical sorted temperature curve
  - result of a simulation
  - may vary from year to year
Life expectancy calculation for temperature profile: ISO 13760 ‘Miner’s Rule’

Using the sorted temperature profile shown, assuming a pressure of 6 bar and including a safety factor of 1.4 the ISO 13760 ‘Miner’s Rule’ allows to estimate the life expectancy of different plastic materials as follows:

<table>
<thead>
<tr>
<th>Material</th>
<th>PE-X</th>
<th>PB</th>
<th>PE-RT (type 2)</th>
<th>PP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life expectancy</td>
<td>&gt; 100 years</td>
<td>&gt; 100 years</td>
<td>100 years *)</td>
<td>5 years</td>
</tr>
</tbody>
</table>

*) Type 1: << 100 ys

Conclusion: PE-X, PB and PE-RT perfectly suitable for heat storage?
For polymers: heat aging of polymers depends massively on the peak temperatures.

For the example given:

- the peak temperature of 97°C occurs only 2 hours/year
- but causes almost half of the heat aging!

<table>
<thead>
<tr>
<th>T</th>
<th>h/year</th>
<th>years</th>
<th>time fraction</th>
<th>heat aging fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>97</td>
<td>2</td>
<td>0.007</td>
<td>0.02%</td>
<td>44.67%</td>
</tr>
<tr>
<td>95</td>
<td>8</td>
<td>0.027</td>
<td>0.09%</td>
<td>36.55%</td>
</tr>
<tr>
<td>93</td>
<td>11</td>
<td>0.038</td>
<td>0.13%</td>
<td>10.10%</td>
</tr>
<tr>
<td>90.5</td>
<td>61</td>
<td>0.209</td>
<td>0.70%</td>
<td>7.36%</td>
</tr>
<tr>
<td>87.5</td>
<td>104</td>
<td>0.356</td>
<td>1.19%</td>
<td>1.06%</td>
</tr>
<tr>
<td>85.5</td>
<td>135</td>
<td>0.462</td>
<td>1.54%</td>
<td>0.26%</td>
</tr>
<tr>
<td>81.5</td>
<td>173</td>
<td>0.59</td>
<td>1.97%</td>
<td>0.01%</td>
</tr>
<tr>
<td>75</td>
<td>981</td>
<td>3.36</td>
<td>11.20%</td>
<td>0.00%</td>
</tr>
<tr>
<td>65</td>
<td>1489</td>
<td>5.10</td>
<td>17.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>55</td>
<td>1270</td>
<td>4.35</td>
<td>14.50%</td>
<td>0.00%</td>
</tr>
<tr>
<td>45</td>
<td>1130</td>
<td>3.87</td>
<td>12.90%</td>
<td>0.00%</td>
</tr>
<tr>
<td>35</td>
<td>332</td>
<td>1.14</td>
<td>3.79%</td>
<td>0.00%</td>
</tr>
<tr>
<td>&lt; 35</td>
<td>3064</td>
<td>10.49</td>
<td>34.98%</td>
<td>0.00%</td>
</tr>
<tr>
<td>sum</td>
<td>8760</td>
<td>30.00</td>
<td>100.00%</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

(exact data from PE-X, but the principle is valid for all other polymers)
⇒ Assessment of the impact of deviations from a simulated temperature profile is crucial!

Results of a parameter study varying temperature and the time of exposure (again for an operational pressure of 6 bar and a safety factor of 1.4):

<table>
<thead>
<tr>
<th>Material</th>
<th>PE-X</th>
<th>PB</th>
<th>PE-RT (type 2)</th>
<th>PP</th>
</tr>
</thead>
<tbody>
<tr>
<td>temperature profile as shown but: T+2K</td>
<td>&gt;&gt; 100 years</td>
<td>100 years</td>
<td>24 years</td>
<td>&lt; 1 year</td>
</tr>
<tr>
<td>temperature profile as shown but: 6h (instead 2h) at 97°C 24h (instead 8h) at 95°C 33h (instead 11h) at 93°C</td>
<td>&gt;&gt; 100 years</td>
<td>150 years</td>
<td>31 years</td>
<td>&lt; 1 year</td>
</tr>
</tbody>
</table>

- minimal temperature increase results in insufficient life expectancy/safety factor of PE-RT
- only PB and PE-X are sufficiently resistant to heat aging
Resistance against external action

On civil engineering construction sites:
- BHE’s are subjected to external action during transport, handling and installation.
- despite treating the pipes with maximum respect the occurrence of scratches and as result after installation a continuous punctual load on the pipe could never be excluded.

If a polymer pipe with a scratch is subjected to internal pressure, slow crack growth may occur.

Slow crack growth correlates directly to the full notch creep test (FNCT) acc. to ISO/FDIS 16770. The FNCT defines the time until a specimen fails. Typical values of FNCT are given in table 4:

<table>
<thead>
<tr>
<th>Material</th>
<th>PE-X</th>
<th>PB</th>
<th>PE-RT (type 2)</th>
<th>PE 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>FNCT</td>
<td>&gt; 20,000 h (no break detected yet)</td>
<td>500 h</td>
<td>250 h</td>
<td>500 – 3000 h</td>
</tr>
</tbody>
</table>
Punctual loads

Punctual loads cause may cause cracks at the inner layer of the pipe, propagating through the pipe wall and eventually resulting in a pipe failure.

Effects of punctual load

Cracks as a result of a punctual load

FNCT requirement for resistance against punctual loads: \( \geq 2,000 \, \text{h} \)

Conclusion:
• PB and PE-X qualify for UTES applications at high temperatures (close to 100°C)
• PE-X exhibits massively superior resistance against external action compared to PB
State of the art: fused BHE end

Joints are always potential failure causes

Failure may occur even weeks after successful pressure tests:
RAUGEO Xa BHE

- cross-linked Polyethylene (PE-Xa)
- extremely tough, no crack growth
- jointless
- glass fiber reinforced plastic covering the BHE end:
  - protection of the BHE end when inserting into the borehole
Summarizing it becomes obvious that joint less PE-X BHE’s are the best choice for high temperature UTES:

<table>
<thead>
<tr>
<th>Material / design</th>
<th>PE-X joint less</th>
<th>PE-X with joints</th>
<th>PB</th>
<th>PE-RT (type 2)</th>
<th>PP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance to internal pressure at elevated temperature / heat aging</td>
<td>+++</td>
<td>+++</td>
<td>++</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Resistance against external action</td>
<td>+++</td>
<td>+++</td>
<td>+</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Joint failure probability</td>
<td>+++</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>