Electrical Insulation for High-Temperature, Cryogenic, and Other Harsh Environments

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High-Temperature Tools and Drilling

High-Temperature Motor Windings for Downhole Pumps Used in Geothermal Energy Production

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This presentation does not contain any proprietary confidential, or otherwise restricted information.
Project Overview

• Goal: Develop and demonstrate high-temperature ESP motor windings for use in Enhanced Geothermal Systems and operation at 300°C

• Timeline
  – Start date: October 1, 2008
  – End date: December 31, 2010

• Budget
  – Total budget: $1,237,489
  – DOE share: $987,739, awardee share: $249,750

• Barriers: Barrier K, Downhole Pumps
  – Pumps capable of providing the necessary flow rate at temperature, depth, and pressure

• Partners:
  – Wood Group ESP
  – New England Wire
EGS reservoirs can be up to 10 kilometers deep

One key challenge for EGS involves lifting geothermally-heated fluids to the surface

Existing ESP’s do not operate reliably at EGS temperatures
  - Failures in motors currently account for 32% of ESP service interruptions, and that will be exacerbated at EGS well temperatures.\(^1\)
  - Mechanical and dielectric properties of the electrical insulations degrade at elevated temperatures.

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<table>
<thead>
<tr>
<th>ESP System Component (Primary Failed Item)</th>
<th>Percentage of total failures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assembly (non-specific)</td>
<td>1</td>
</tr>
<tr>
<td>Cable</td>
<td>21</td>
</tr>
<tr>
<td>Sensor</td>
<td>1</td>
</tr>
<tr>
<td>Gas Handler</td>
<td>1</td>
</tr>
<tr>
<td>Motor</td>
<td>32</td>
</tr>
<tr>
<td>Pump</td>
<td>30</td>
</tr>
<tr>
<td>Intake</td>
<td>4</td>
</tr>
<tr>
<td>Seal/Protector</td>
<td>10</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
</tr>
</tbody>
</table>

Scientific/Technical Approach

• Designed and tested composite insulations for use in high-temperature motors
  – Conditioned at 300°C
  – Tested at 250°C
• Down-selected candidate insulations that show best high-temperature electrical performance in laminate form (completed 7/09)
  – Go decision based on satisfactory results from initial testing
• Demonstrated capability to continuously apply insulation to wires (completed 10/09)
• Qualify motor windings using down-selected insulations (in progress, plan to complete 12/10)
ESP Motors

- Electrical insulation provides both turn-to-turn and turn-to-ground protection
- Motors operate at 3-5 kV
- Wire insulations are as thin as possible to provide for higher conductor volume
- PEEK is currently used to insulate some ESP motor wires
  - Used as insulation for comparison purposes
Technology Innovation

• ESP’s are de-rated for high-temperature operation
  – Due to decreased resistivity of the insulation
  – Causes equipment to operate below nameplate rating
  – Reduces process efficiency
• CTD and Wood Group ESP are developing motors for operation at 300°C for 3+ years
• CTD has developed NANUQ® inorganic-based composite insulation materials
  – Compatible with existing motor fabrication processes
  – Based on a technology previously developed and patented by CTD
• Initial results show CTD’s insulation performs significantly better than PEEK at 250°C
  • After conditioning at 300°C
Year 1 Results
Insulation Application Processes

- Designed and commissioned facilities for insulation application
  - Apply fiber reinforcements onto 8 to 12 AWG copper wire
  - Apply inorganic resins to wire using continuous process
  - Cure resin in-line
- Advantages of inorganic composite insulations
  - Composite approach provides mechanical durability
  - Thermosetting resins do not re-flow at elevated temperatures
## Year 1 Results
### Improved Performance at 250°C

<table>
<thead>
<tr>
<th>Property</th>
<th>PEEK</th>
<th>CTD-1203XC</th>
<th>CTD-1205X</th>
<th>CTD-1210XC</th>
<th>CTD-1215XP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dielectric Strength (kV/mm)</td>
<td>20</td>
<td>70</td>
<td>67</td>
<td>61</td>
<td>79</td>
</tr>
<tr>
<td>Electrical Strength Constant (kV/mm$^{1/2}$)</td>
<td>15</td>
<td>54</td>
<td>46</td>
<td>41</td>
<td>53</td>
</tr>
<tr>
<td>Resistivity at 5 kV (GΩ-cm)</td>
<td>15</td>
<td>512</td>
<td>670</td>
<td>234</td>
<td>467</td>
</tr>
</tbody>
</table>
Year 1 Results
High-Temperature Testing Apparatus

- Established apparatus for thermal conditioning of motor windings
  - Accommodates up to three statorettes
  - Expose statorettes (or wires) to elevated temperatures (up to 300 °C) for extended periods of time
  - Post-exposure electrical testing
  - Follows IEEE and ASTM standard practices
- Device currently in use for statorette conditioning and testing
Year 2 Activities (Ongoing)
Statorette Fabrication and Testing

- Statorette testing
  - Enables testing and qualification of new insulations in relevant configuration
  - Subjects wire to same strains associated with full scale motor assembly

- Same cross-section as ESP motor winding

- Uses wires insulated with continuous production process

- Thermal conditioning tests are ongoing
Key accomplishments from the past year include:

- Demonstrated electrical insulations with significantly higher dielectric breakdown strengths and resistivities than PEEK at 250°C
  - After thermal conditioning at 300°C
- Established capability for applying composite insulations to continuous lengths of wire
- Fabricated high-temperature test apparatus for characterization of insulations
- Began fabricating and testing sub-scale motor windings (statoretettes)
Project Management/Coordination

• Project management activities
  – Oversight of technical work
  – Establish priorities of technical support staff
  – DOE reporting and documentation requirements
  – Budget management

• Coordination of work with collaborators and vendors
  – Communication with Wood Group ESP (industry partner)

• Project integration
  – Leverages a CTD SBIR program to design and build high-temperature electrical cables for EGS applications (downhole power distribution)
Future Directions

• Insulation system optimization continues
  – Final fiber and matrix selection
  – Demonstrate suitability of wire to meet full scale motor winding processes
  – Qualify to ASTM standards as well as customer-specific requirements

• High-temperature electrical testing, as well as thermal conditioning of statorettes, are ongoing

• Work with motor customers to build full scale motor prototypes
Summary

• Composite insulations with high-temperature electrical properties superior to PEEK have been demonstrated
  – Insulations offer improved breakdown strength and resistivity at 250°C

• Methods for applying the insulations to continuous lengths of wire have been demonstrated

• Ongoing/future work involves the fabrication and testing of motor windings
  – Winding of motors
  – Thermal conditioning tests
Supplemental Slides