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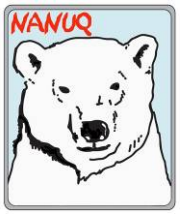
COMPOSITE TECHNOLOGY DEVELOPMENT, INC.
ENGINEERED MATERIAL SOLUTIONS

WOOD GROUP




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

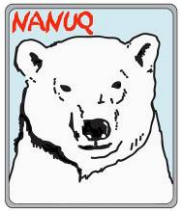
## High-Temperature Motor Windings for Downhole Pumps Used in Geothermal Energy Production

May 18, 2010

**Matthew Hooker**
**Composite Technology Development, Inc.**
High-Temperature Tools and Drilling

# Project Overview

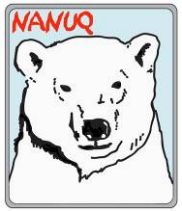





- Goal: Develop and demonstrate high-temperature ESP motor windings for use in Enhanced Geothermal Systems and operation at 300°C
- Timeline
  - Start date: October 1, 2008
  - End date: December 31, 2010
- Budget
  - Total budget: $1,237,489
  - DOE share: $987,739, awardee share: $249,750
- Barriers: Barrier K, Downhole Pumps
  - Pumps capable of providing the necessary flow rate at temperature, depth, and pressure
- Partners:
  - Wood Group ESP
  - New England Wire

# Relevance/Impact of Research





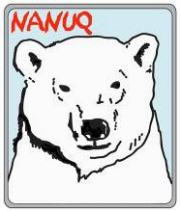

- EGS reservoirs can be up to 10 kilometers deep
- One key challenge for EGS involves lifting geothermally-heated fluids to the surface
- Existing ESP's do not operate reliably at EGS temperatures
  - Failures in motors currently account for 32% of ESP service interruptions, and that will be exacerbated at EGS well temperatures.[1]
  - Mechanical and dielectric properties of the electrical insulations degrade at elevated temperatures.

| ESP System Component (Primary Failed Item) | Percentage of total failures |
|---|---|
| Assembly (non-specific) | 1 |
| Cable | 21 |
| Sensor | 1 |
| Gas Handler | 1 |
| Motor | 32 |
| Pump | 30 |
| Intake | 4 |
| Seal/Protector | 10 |
| Other | 1 |

[1] **N. Griffiths and S. Breit, "The World's First Wireline Retrievable Electric Submersible Pumping System," presented at the European Artificial Lift Forum, Aberdeen, Scotland, February 28, 2008.**

# Scientific/Technical Approach



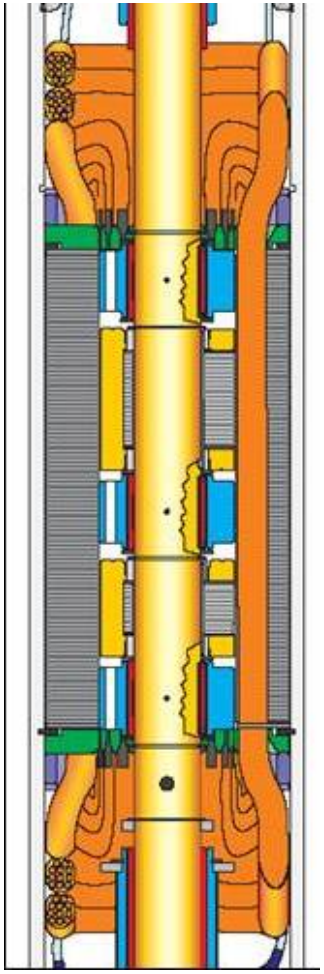


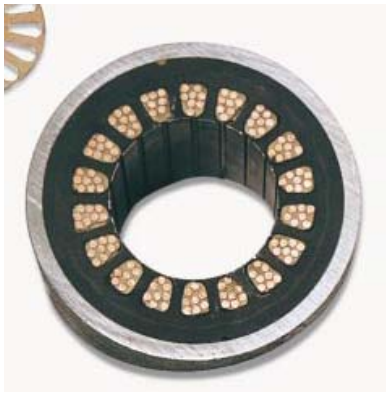

- Designed and tested composite insulations for use in high-temperature motors
  - Conditioned at 300°C
  - Tested at 250°C
- Down-selected candidate insulations that show best high-temperature electrical performance in laminate form (completed 7/09)
  - Go decision based on satisfactory results from 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

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- ESP's are de-rated for high-temperature operation
  - Due to decreased resistivity of the insulation
  - Causes equipment to operated 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

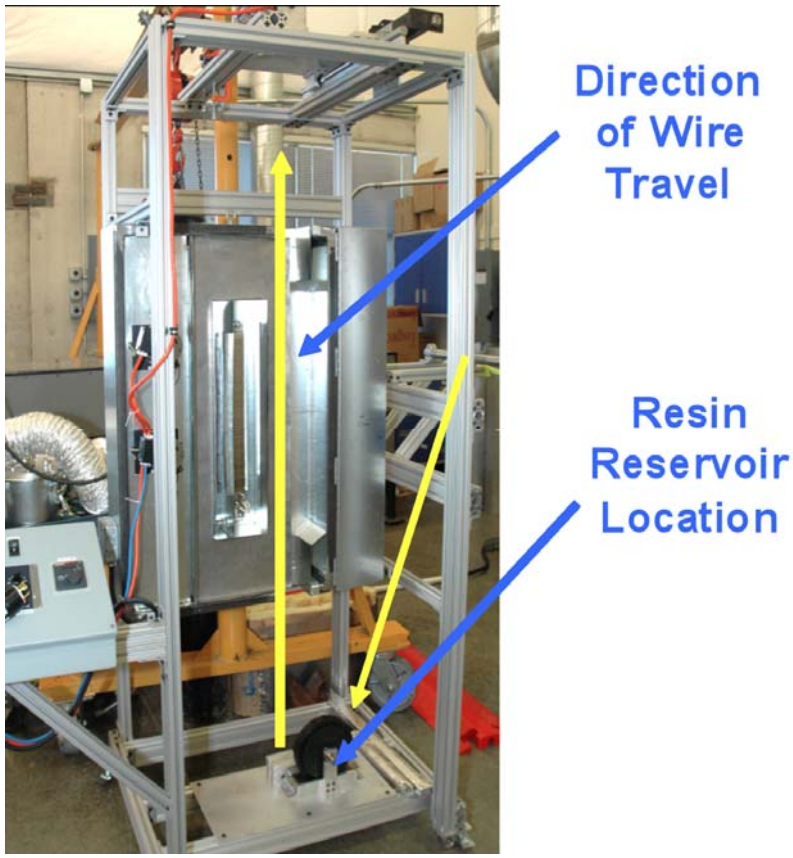

CTD-1203X


PEEK

# Year 1 Results
# Insulation Application Processes

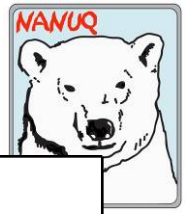


- Designed and commissioned facilities for insulation application
  - Apply fiber reinforcements onto 8 to 12 AWG copper wire
  - Apply inorganic resins to wire using continuous process
  - Cure resin in-line
- Advantages of inorganic composite insulations
  - Composite approach provides mechanical durability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



# Year 1 Results
# Improved Performance at 250°C






| | PEEK | CTD-1203XC | CTD-1205X | CTD-1210XC | CTD-1215XP |
|---|---|---|---|---|---|
| Dielectric Strength (kV/mm) | 20 | 70 | 67 | 61 | 79 |
| Electrical Strength Constant ($kV/mm^{1/2}$) | 15 | 54 | 46 | 41 | 53 |
| Resistivity at 5 kV (GΩ-cm) | 15 | 512 | 670 | 234 | 467 |

# Year 1 Results
# High-Temperature Testing Apparatus

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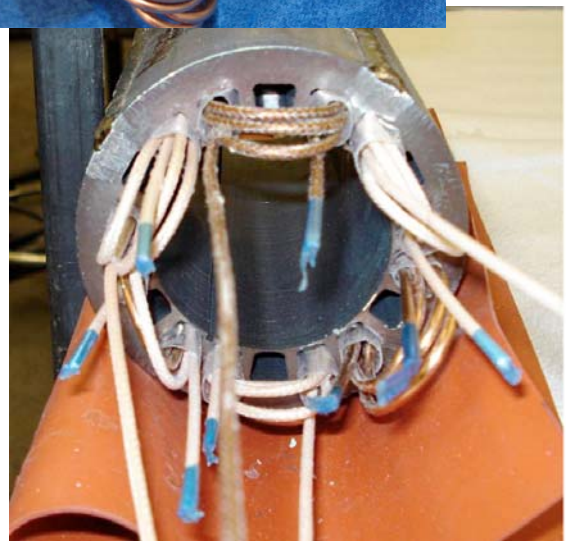
- Established apparatus for thermal conditioning of motor windings
  - Accommodates up to three statorettes
  - Expose statorettes (or wires) to elevated temperatures (up to 300 °C) for extended periods of time
  - Post-exposure electrical testing
  - Follows IEEE and ASTM standard practices
- Device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

# Year 2 Activities (Ongoing)
# Statorette Fabrication and Testing

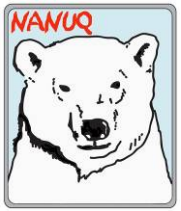


- Statorette testing
  - Enables testing and qualification of new insulations in relevant configuration
  - Subjects wire to same strains associated with full scale motor assembly
- Same cross-section as ESP motor winding
- Uses wires insulated with continuous production process
- Thermal conditioning tests are ongoing



# Accomplishments, Expected Outcomes and Progress

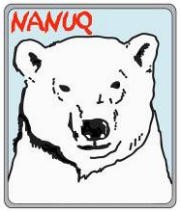





- Key accomplishments from the past year include:
  - Demonstrated electrical insulations with significantly higher dielectric breakdown strengths and resistivities than PEEK at 250˚C
    - After thermal conditioning at 300˚C
  - Established capability for applying composite insulations to continuous lengths of wire
  - Fabricated high-temperature test apparatus for characterization of insulations
  - Began fabricating and testing sub-scale motor windings (statoretettes)

# Project Management/Coordination

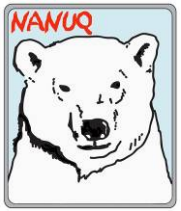





- Project management activities
  - Oversight of technical work
  - Establish priorities of technical support staff
  - DOE reporting and documentation requirements
  - Budget management
- Coordination of work with collaborators and vendors
  - Communication with Wood Group ESP (industry partner)
- Project integration
  - Leverages a CTD SBIR program to design and build high-temperature electrical cables for EGS applications (downhole power distribution)

# Future Directions

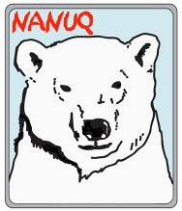




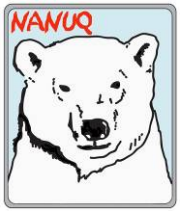

- Insulation system optimization continues
  - Final fiber and matrix selection
  - Demonstrate suitability of wire to meet full scale motor winding processes
  - Qualify to ASTM standards as well as customer-specific requirements
- High-temperature electrical testing, as well as thermal conditioning 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

# Publications





- M.W. Hooker, C.S. Hazelton, K.S. Kano, M.L. Tupper, and S. Breit, “High-Temperature Electrical Insulations for EGS Downhole Equipment,” presented at the Stanford Geothermal Workshop, Feb. 1-3, 2010.

- Matthew W. Hooker, Craig S. Hazelton, Kimiko S. Kano, Larry G. Adams, Michael L. Tupper, and Steven Breit, “Novel High-Temperature Materials Enabling Operation of Equipment in Enhanced Geothermal Systems,” presented at Energy 2010, Cocoa Beach, FL, February 2010