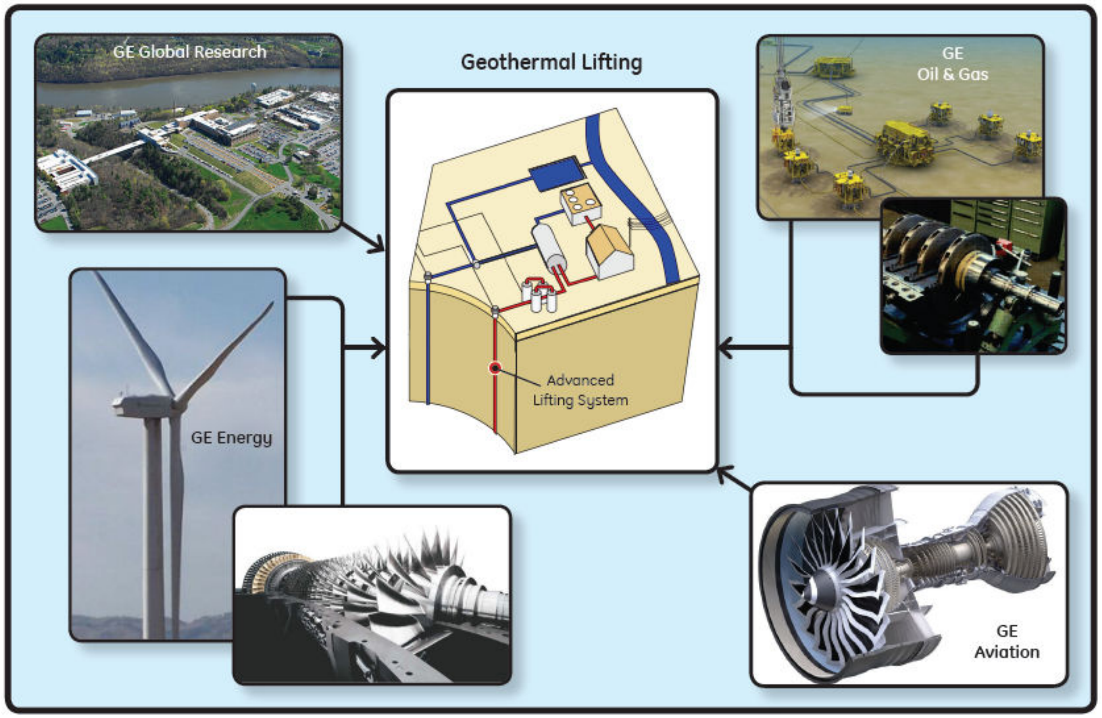

High-Temperature-High-Volume Lifting for Enhanced Geothermal Systems

April 22 25, 2013

Norman Turnquist
GE Global Research

High Temperature Tools and Sensors, Down hole Pumps and Drilling

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

Relevance/Impact of Research

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Overall objective: Advance the technology for well fluids lifting systems to meet the foreseeable pressure, temperature, and longevity needs of the Enhanced Geothermal Systems (EGS) industry.

- Define the temperature, pressure, and flow rate requirements for geothermal fluid lifting systems for the next 10 years
- Evaluate alternative lifting methods
- Develop high-temperature (>300ºC), high-power (5 MW) lifting system component technology to meet the requirements. Innovations include:
    - Novel ESP arrangement / architecture for high flow rate
    - High-temperature motor / materials
    - High volume centrifugal pump
    - Seals / bearings

Success of the program will serve to:

•Extend geothermal technology to geographic areas that are not candidates for conventional geothermal power production (depths up to 10 km)

•Reduce dependence on fossil fuels with accompanying reduction in carbon emissions

Scientific/Technical Approach

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Three-phased Approach:

1. Define system requirements, evaluate lifting methods, downselect and identify technical barriers. (Milestone GO/NO GO – 09/2010) - DONE
   - Established via consultation with AltaRock, site visits
   - ESP identified for development (high temperature, high power)
   - ***High-temperature motor identified as the key enabling technology***

2. Develop materials, components, and other technologies that will meet the system requirements. (Milestone GO/NO GO – 03/2012) - DONE
   - Permanent magnet motor design for high power density and thermal management
   - Centrifugal pump optimized for high flow rate
   - High-temperature motor materials established
   - Seal / bearing component designs established

3. Demonstrate subscale prototype under simulated conditions. (Complete 12/2013)
   - Subscale prototype design completed; fabrication underway
   - Motor thermal testing pending completion of motor fabrication (added to plan)
   - Flow loop completed and fabricated; installation underway
   - Motor / pump demonstration in flow loop (moved out to accommodate thermal test)

Accomplishments, Results and Progress

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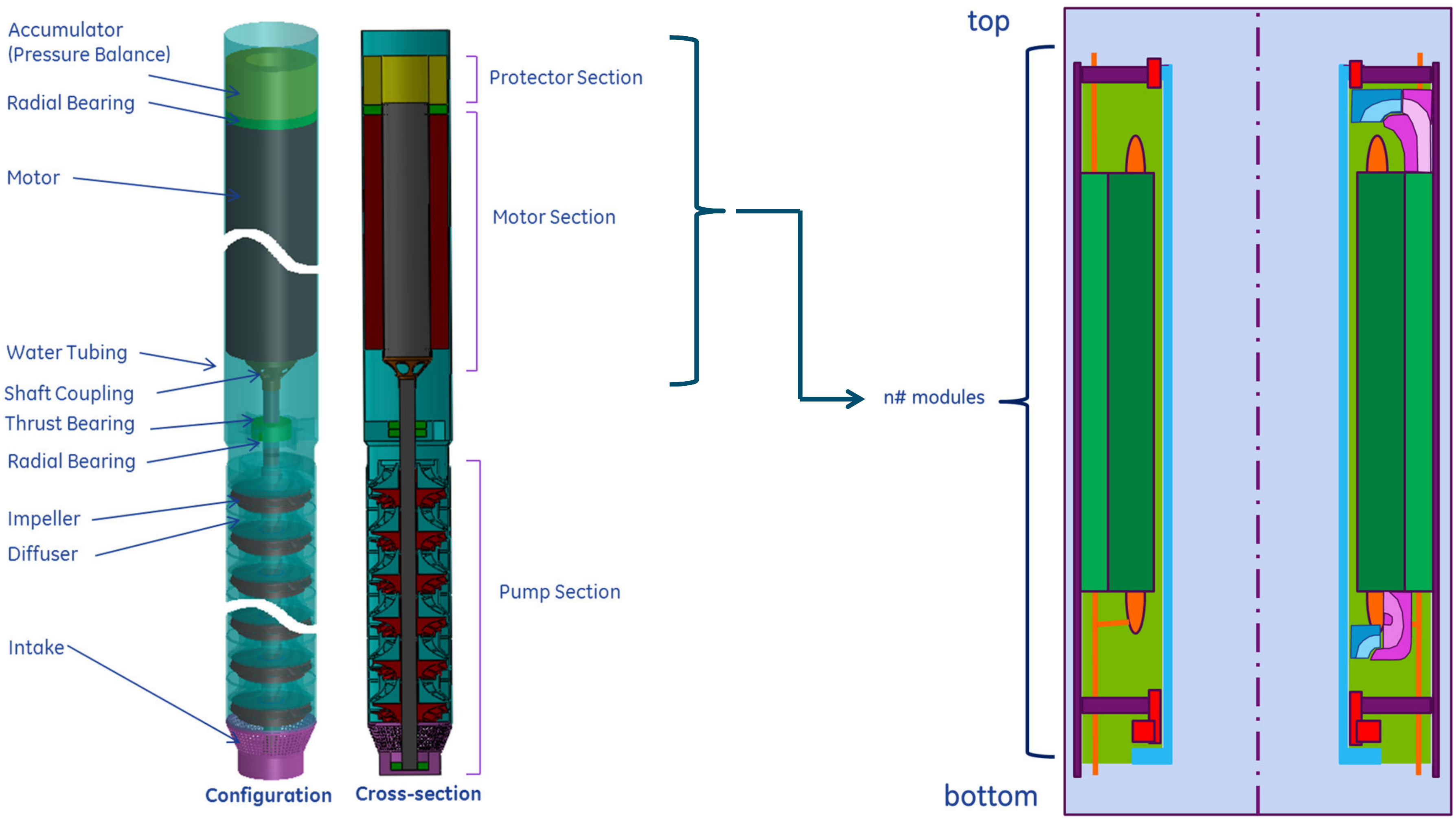
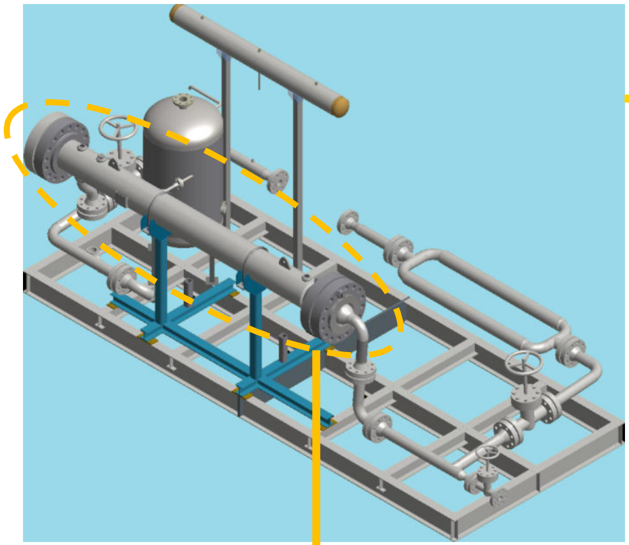
Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Define well fluid lifting system requirements criteria	System specs. established with consultation of AltaRock Energy, geothermal site visits	June 2010
Review alternative lifting systems and their potential for development	Lifting method matrix created; Electric Submersible Pump selected for development	Sept. 2010
Establish conceptual ALS design and Technology Development Plan	Component tech. gaps identified; motor thermal design and insulation mat'ls ID'd as key development needs; high-volume pump, seals, bearings also targeted	Sept. 2010
Execute Technology Development Plan	Motor thermal / electrical design; pump design; insulation / dielectric mat'l testing/selection; seal testing; bearing / rotordynamic design; thrust washer testing	July 2012
Update ALS concept design and scale it for laboratory demonstration	PM motor design established and released for fabrication; materials procured	Jan. 2012
Create ALS Test & Demonstration Plan and flow loop conceptual design	Flow loop designed, fabricated and delivered to GE; test plan drafted; instrumentation procured	Jan. 2012
Detailed design and fabrication of lab-scale ALS demonstrator	Motor, pump, and test section fabrication underway; oil skid fabricated/tested; thermal test hardware procured and installed.	(May 2013)
Detailed design and fabrication of flow loop	Flow loop installation in final stages (no-cost time extension approved)	(May 2013)
Lab-scale ALS demonstration	Motor thermal test added to demonstration plan; system demo. to follow (no-cost time extension approved)	(Dec. 2013)

Conceptual ESP Design



Geothermal ESP - Flow Loop



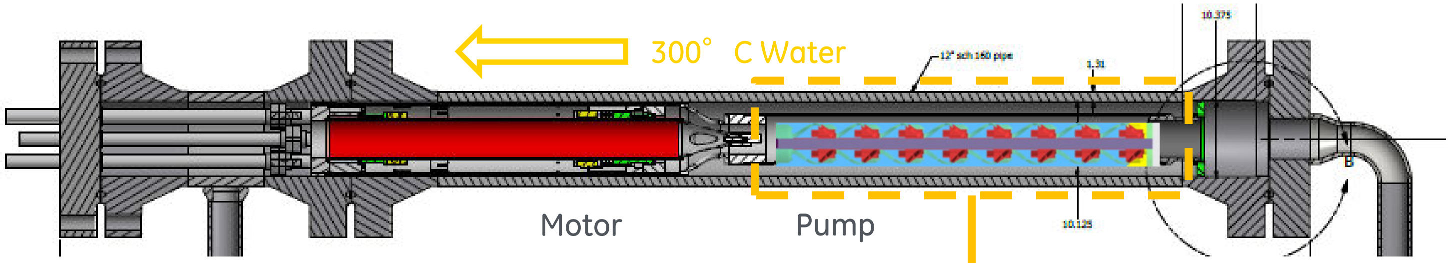
Geothermal
ESP Flow Loop

Main Loop

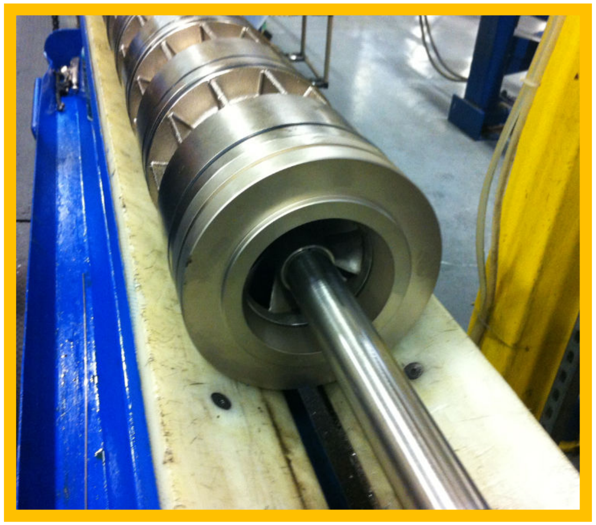
Test Section

Geothermal ESP - Pump

Test Section Cross-section View



Impellers and Diffusers



Pump Assembly

Geothermal ESP - Motor

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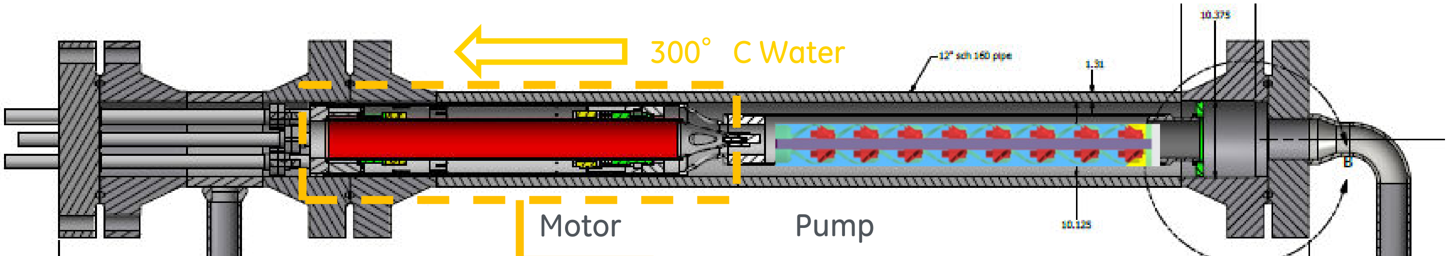
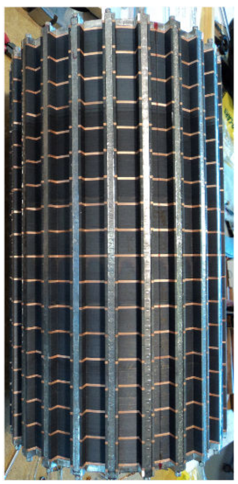
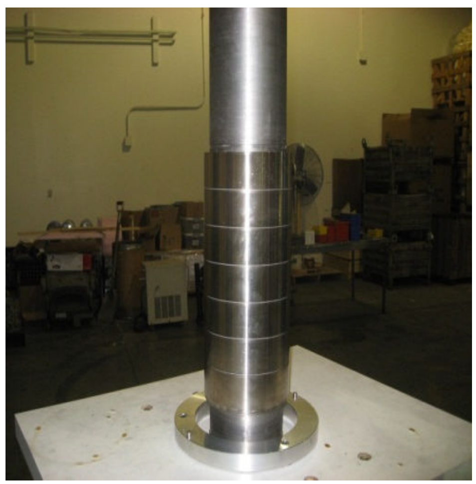
Test Section Cross-section View

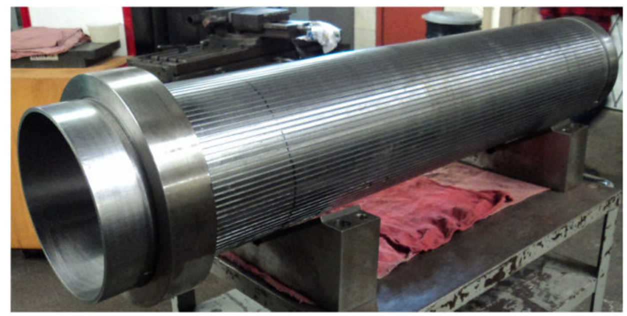




Stator



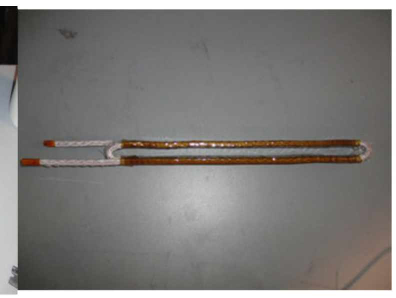
Rotor



Motor Housing

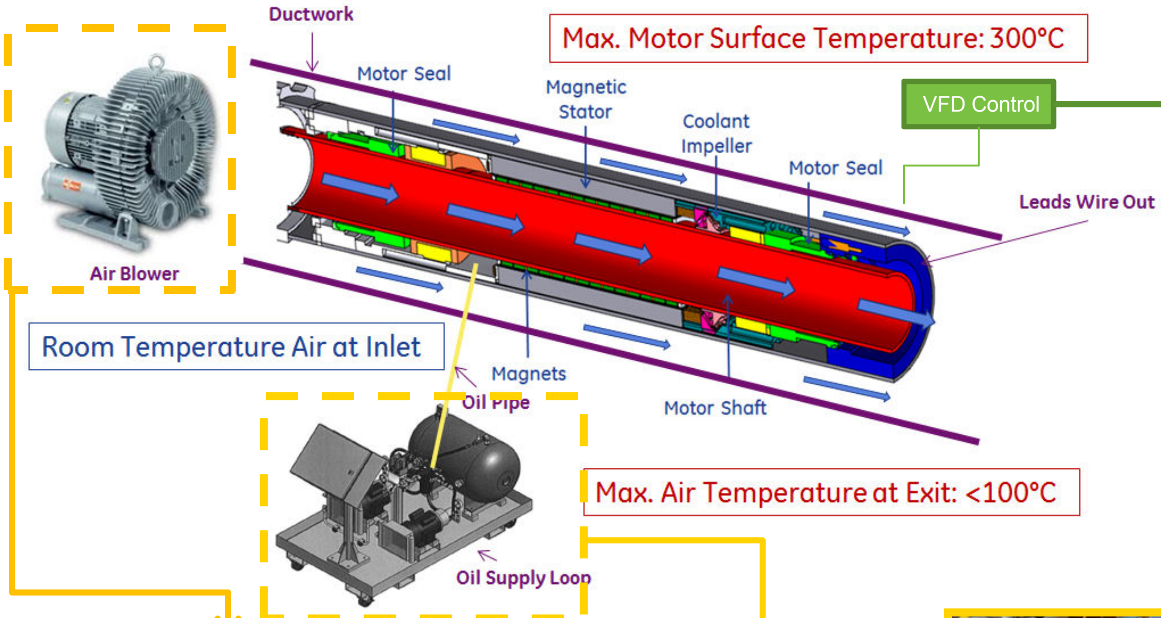
Bearings

Seal



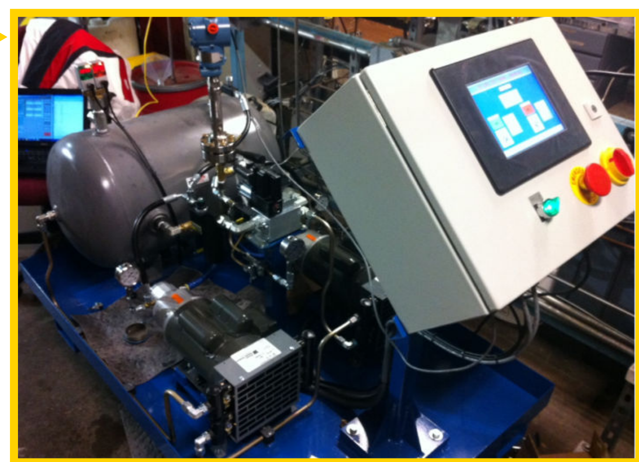
Winding

Geothermal ESP – Thermal Test



VFD

Air Blower



Oil Supply Loop

Component Development

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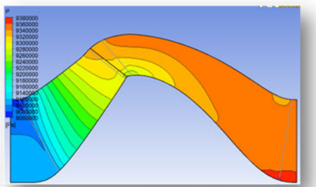
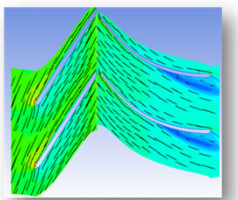
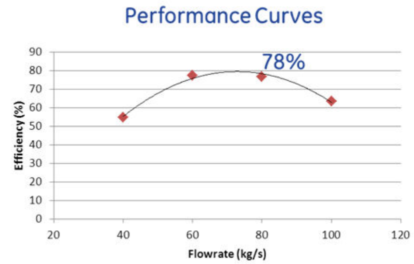
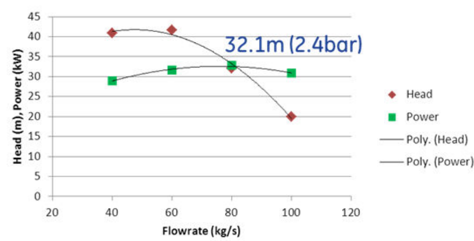


Pressure distribution @ Meridional view

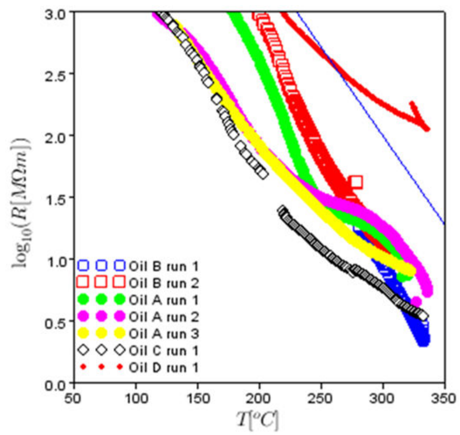


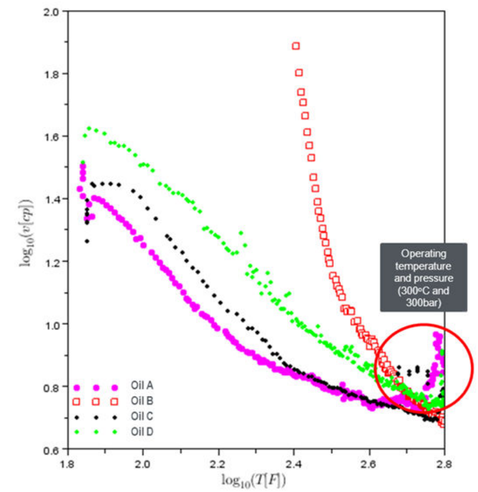
Velocity distribution @ 50% span



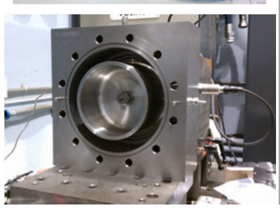


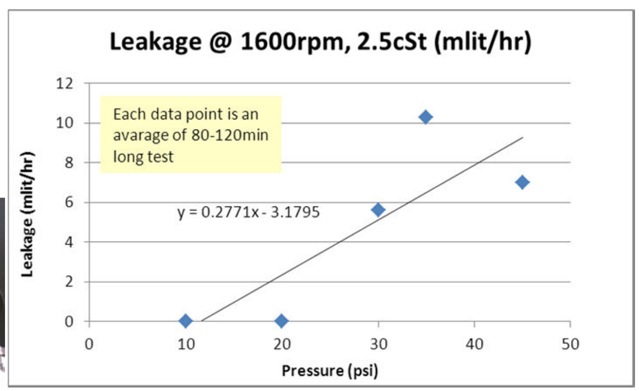
Pump stages optimized for high flow rate



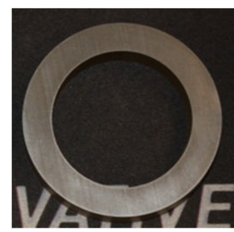


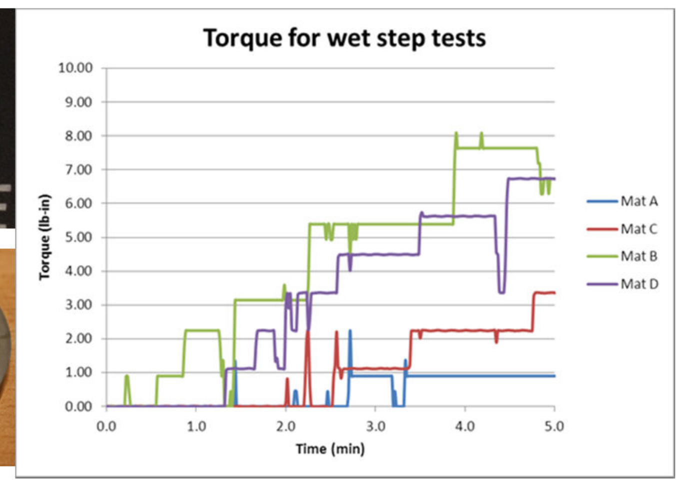
Candidate oil resistivity / viscosity quantified at elevated temperature.





Seal performance quantified via rig testing.





Pump thrust washer material testing.

Component Development

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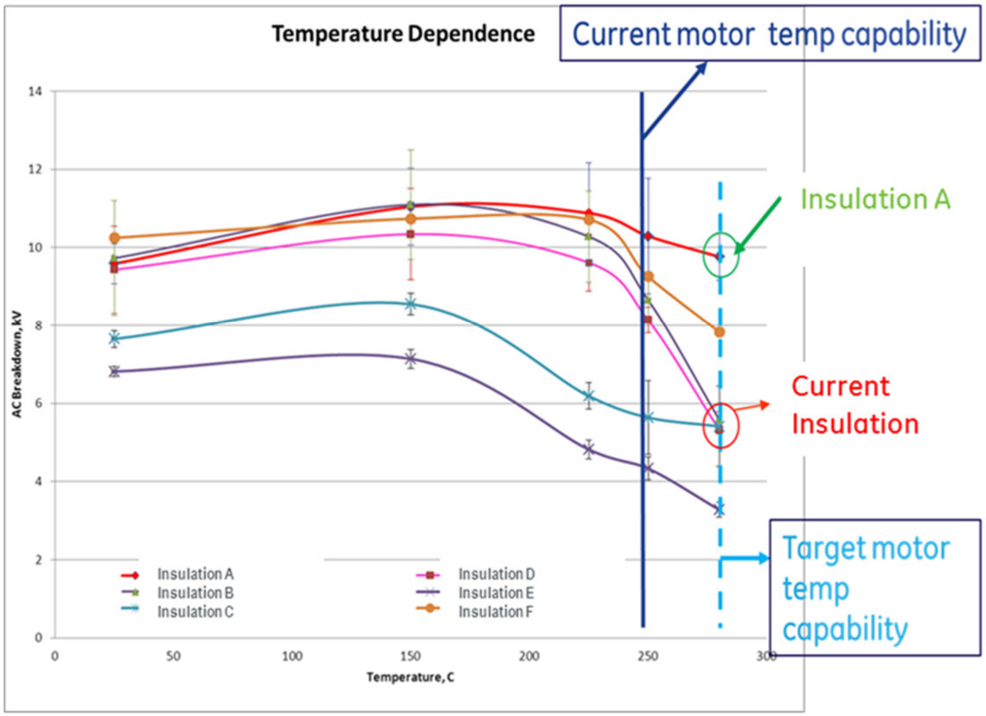

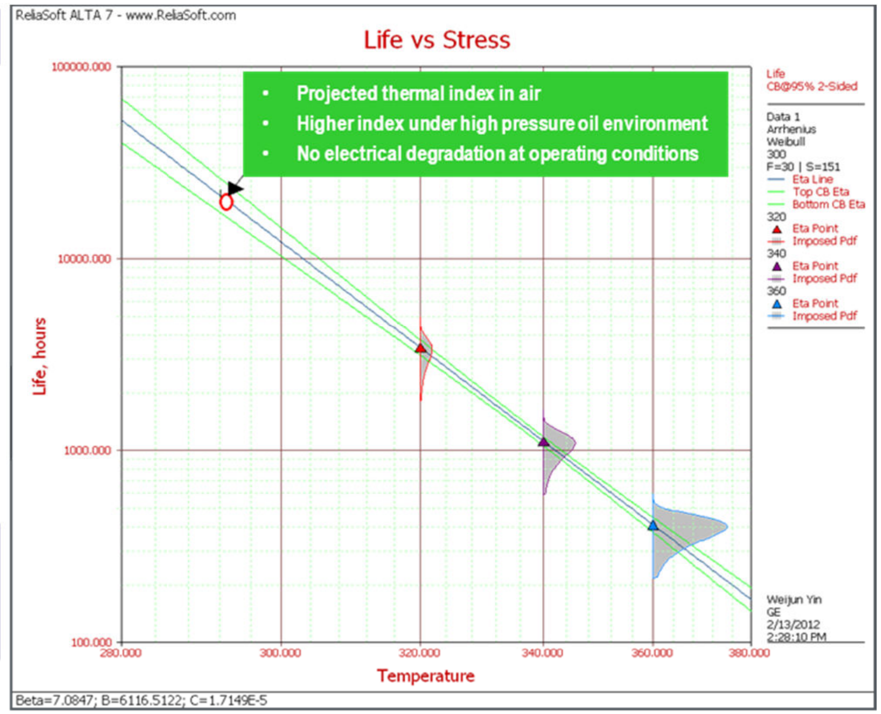

GE Nanocomposite enameled wire and Insulation "A" film show good dielectric performance at elevated temperature.

Accomplishments, Results and Progress

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- Accomplishments / Progress to date
  - System requirements established (in Phase 1)
  - Lifting methodology and technical barriers identified (in Phase 1)
    - *Greatest technical challenge → High temperature motor technology*
    - *System requires 5MW/300C (vs. ~1.5MW/250C state-of-the-art)*
  - System conceptual design established (in Phase 2)
  - Component development completed (in Phase 2)
    - Motor thermal and electrical design
    - Insulation and dielectric cooling fluids tested/downselected
    - Seal and thrust washer testing completed
    - Bearing selection / rotordynamic analyses completed
    - Pump optimized via CFD Design-of-Experiments
  - Subscale motor and pump fabrication nearly complete (Phase 3)
  - Subscale flow loop test facility designed, fabricated; installation underway (Phase 3)
  - Motor thermal test introduced to test plan to address main technical challenge (Phase 3)
    - *Motor thermal test configuration designed ; hardware installed*
    - *Program schedule extended to address motor thermal risk*
  - 2012 Best Presentation Award – Geothermal Resource Council, Oct. 2012
  - 2012 Best Paper of the Year Award – Renewable Energy World, Dec. 2012
  - (5) patent dockets filed

Future Directions

- 2013 Plan
  - Complete motor fabrication
  - Demonstrate high temperature capability via motor thermal test in air
  - Complete subscale flow loop commissioning (facility connections, DAQ)
  - Assemble motor/pump system and install test section into flow loop
  - Demonstrate system capability via subscale flow loop test *
  - * Alternate plan is perform additional thermal tests and refine cooling scheme, if initial thermal test shows that is necessary

- Future Research
  - Scale up subscale prototype for possible Phase 4 field demonstration

- Original program completion date of June 2013 extended to December 2013 to accommodate added motor thermal testing.

Milestone or Go/No-Go	Status & Expected Completion Date
Complete motor fabrication	Nearly complete as of 03/01/2013
Motor thermal test	Pending; planned for completion May, 2013.
Commission flow loop	Installation underway; planned complete May, 2013.
Flow loop test	All testing planned for completion by Dec. 2013.

Mandatory Summary Slide

- Program is on schedule for completion by December 2013
  - Schedule extended to include motor thermal testing
  - Minimizes risk associated with highest-risk program element
- Technology advances include:
  - High temperature modular ESP motor technology (for 300C fluid)
    - Motor optimized for thermal management to minimize internal temperatures
    - High-temperature insulation / materials system for up to 330° C
    - High-temperature seals / bearings
    - Modular ESP system for up to 5MW
  - High volume flow pump technology (for 80 kg/s)
    - Novel inverted, flow-through-the-bore ESP configuration
    - High-efficiency pump impeller/diffuser design
- Program funding supplemented by GE internal funding with full support of GE Artificial Lift business
  - All program decisions / directions reviewed regularly with GE AL

Project Management

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Timeline:

Planned Start Date	Original Planned End Date	Actual Start Date	Current End Date
April 01, 2010	June 30, 2013	April 01, 2010	December 31, 2013*

* No-cost time extension approved

Budget:

Federal Share	Cost Share	Planned Expenses to Date	Actual Expenses to Date	Value of Work Completed to Date	Funding needed to Complete Work
$2,390,210	$597553	$2506733 (83.9%)	$2650212 (88.7%)	$2650212	$481003

- Leveraging other programs:
  - Consultation with AltaRock Energy on system requirement definition
  - Separate DOE effort on cable technology
- Full support and involvement of GE Artificial Lift business
- Remainder of 2013 focused on:
  - Subscale system fabrication completion
  - Motor thermal testing
  - Flow loop installation – GE Internal funding
  - System flow testing – Supplemental GE Internal funding