Hotline IV – High Temperature ESP

May 18, 2010

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Project Overview

• Timeline  Start  End  % Completion
  – DOE Project  1-Sep-2008  31-Mar-2010  100%
  – Actual  1-Jan-2007  31-Dec-2010  81%

• Budget  (Sep 2008 through Mar 2010)
  – Total project spend: $2.459M
  – DOE share: $1.254M (51%)
  – Awardee share: $1.205M (49%)
  – 2009 DOE funding: $1.254M; 2010: $0, (funding received and/or available)

• Full Budget  (Jan 2007 through Dec 2010)
  – Total project spend: $4.638M (through Mar 2010)
  – DOE share: $1.254M (27%)
  – Awardee share: $3.384M (73%)

• Partners: None
Relevance/Impact of Research

- A submersible pump that meets the requirements is essential for EGS economics.
  - High temperature rating ensures maximum power per unit fluid
  - High Power ensures maximum fluid per well
  - Reliability ensures avg. pump replacement cost and downtime are acceptable

- Objective: Increase temperature rating of high temperature ESP’s

- Results
  - Designed and built system rated for 250C fluid temperature and 300C internal temperature
  - Tested up to 260C fluid temperature.
  - Significant Technology barrier to go to higher temperatures (still working on it!)

<table>
<thead>
<tr>
<th></th>
<th>Fluid Temp</th>
<th>Internal Temp</th>
<th>Power</th>
<th>Runlife</th>
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<tbody>
<tr>
<td>Requirement</td>
<td>300C</td>
<td>?</td>
<td>2000HP</td>
<td>3-years</td>
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<tr>
<td>HT ESP</td>
<td>218C</td>
<td>288C</td>
<td>320HP</td>
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<td>205C</td>
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Scientific/Technical Approach

- Management Process (SLB Generic Process)

<table>
<thead>
<tr>
<th>Stage</th>
<th>End Checkpoint</th>
<th>Actual Date</th>
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<tr>
<td>Concept</td>
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<td>Development</td>
<td>Commercialization</td>
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<tr>
<td>Close-Out</td>
<td>Project Closed</td>
<td>Mar 2011</td>
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- Increasing Temperature Capability
- Improving Reliability
### Increasing Temperature Ratings

- **Complete re-evaluation of all non-metallic components**
- **Example: Elastomer Compound**

<table>
<thead>
<tr>
<th>Compound</th>
<th>Fluid 1 (250°C)</th>
<th>Fluid 1 (250°C)</th>
<th>Fluid 1 (300°C)</th>
<th>Fluid 1 (300°C)</th>
<th>Fluid 2 (300°C)</th>
<th>Fluid 3 (343°C)</th>
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Scientific/Technical Approach

Improving Reliability

• Balance between failed elements, failure modes, and root causes
  – Failed Elements: What failed on a system that stopped production
  – Failure Modes: What directly caused the element to fail
  – Root Causes: What originally allowed a failure mode to exist

• Project Focus
  – Increasing Redundancy of critical components
  – Mitigate effects of sand entry around critical and rotating components
  – Reduce potential service errors
  – Using internal motor temperature sensor for automated protection
  – Higher Temperature Materials
Scientific/Technical Approach

Management Process

• Concept Phase  Jan-2007 to July 2007
  – Checkpoint: Concept Closure
  – Look to accomplish: List of project requirements and economic value

• Feasibility Phase  Aug 2007 to June 2008
  – Checkpoint: Feasibility Closure
  – Look to Accomplish:
    • Proof that project requirements are technically and economically feasible.
    • Identify important new characteristics and materials.
  – Milestones: Go/No-Go decision based on technical feasibility

• Development Phase  July 2008 to Dec 2010
  – Checkpoint: Commercialization
  – Look to Accomplish: Design, build and test components, sub-assemblies, and assembly
  – Milestones: Functional Test of first prototype, Successful endurance test of prototype, field testing of design

• Close-Out Phase Jan 2011 to Mar 2011
  – Checkpoint: Project Closed
  – Look to Accomplish: Hand over project to sustaining engineering
Accomplishments, Expected Outcomes and Progress

Accomplishments

• Identified Key Changes to improve reliability
• Selected material candidates and tested to determine best option for increasing temperature rating
• Designed, built, and tested three prototype units
• Internal endurance test for 300-hours
• External joint test with ConocoPhillips at C-FER Technologies
  – Temperature up to 260C fluid temp.

DATA TAKEN ON AUGUST 09 2009
Accomplishments, Expected Outcomes and Progress

![Graph showing storage modulus (MPa) vs. temperature (°C). The graph compares Polyimide and PEEK materials.](image-url)
Accomplishments, Expected Outcomes and Progress

TEMPERATURE AS A FUNCTION OF TIME FOR HOTLINE XD HOTLOOP TEST

DATA TAKEN ON AUGUST 09 2009

- Motor oil Temperature
- Mid Rotor Bearing Skin Temperature
- Thrust Bearing Skin Temperature
- SSM Lower Body Skin Temperature

Temperature (ºF) vs. Time (minutes)
Accomplishments, Expected Outcomes and Progress
### Accomplishments, Expected Outcomes and Progress

#### Team

<table>
<thead>
<tr>
<th>Member</th>
<th>Title</th>
<th>Loc</th>
<th>Yrs</th>
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<tr>
<td>Jose Caridad</td>
<td>Mechanical Engineer</td>
<td>SRC</td>
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<td>Michael Dowling</td>
<td>Project Manager</td>
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<td>Jason Kobersky</td>
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<td>Albert Kyin</td>
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<td>Robert Philips</td>
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<tr>
<td>Arthur Watson</td>
<td>Project Team Leader</td>
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<td>Chris Featherby</td>
<td>Designer</td>
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<td>Kevin Cox</td>
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<td>Will Goertzen</td>
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<tr>
<td>Sophie Govetto</td>
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<td>Greg Manke</td>
<td>Cable Eng. Manager</td>
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<tr>
<td>Melissa Vermeer</td>
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<td>Beng Chua</td>
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<tr>
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<tr>
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<td>SPE</td>
<td>2</td>
<td>PhD</td>
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Facilities

• Singapore
  ISO 9001 Certified (2008)
  – Worldwide Manufacturing Center

• Bartlesville, Oklahoma
  API Q1 Certified (2008)
  – Original REDA Headquarters
  – Research and Manufacturing Center
  – High temperature motor test lab

• Lawrence, KS
  ISO 9001:2008 certified
  – Polymer Lab
  – Custom Elastomer Production
  – Cable Production (including electrical connectors)
Project Management/Coordination

• **Schedule**
  – Parallel Development of Power Train and Monitoring System
  – Dealing with the unexpected

• **Resources**
  – Personnel
  – Test Facilities
  – Equipment

• **Project Cooperation**
  – High Temperature Monitoring System developed in parallel and integrated into motor.
Future Directions

• 300-HP, 250C System
  – Continued Development of new elastomer compounds
  – Field Trials approx. Aug 2010 through Dec 2010
  – Commercial Product End 2010
  – Continued monitoring for reliability improvement potential

• 300-HP 300C System
  – Development of components to enable system in 2010
  – Collaborative Work with industry partner on new materials
  – Testing and Field trials present a problem

• High Power System (250C)
  – Apply lessons learned to larger diameter motor
  – Present market in ‘Hydrothermal’ systems in Europe and Western U.S.
  – Target for preliminary design is mid 2011.
Summary

- Successfully designed, built, and tested a new system that...
  - Is capable of permanent operation in 250°C fluid.
  - Will improve on the reliability of the previous system
  - Is capable of 300-HP
- Field Trials will be Aug/Sep 2010 through end of 2010
- Product will be commercial in 2011
- Higher Temperature research will progress in 2010 toward 300°C target.
- High power version is in the works

<table>
<thead>
<tr>
<th>Year</th>
<th>Key Technical Results</th>
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<tbody>
<tr>
<td>2009</td>
<td>• Build Prototype</td>
</tr>
<tr>
<td></td>
<td>• Internal Endurance Test</td>
</tr>
<tr>
<td></td>
<td>• External Endurance Test</td>
</tr>
<tr>
<td>2010</td>
<td>• Release design for manufacturing</td>
</tr>
<tr>
<td></td>
<td>• Field Trials</td>
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Supplemental Slides
Delivered
• None

Planned
• Global Petroleum Conference, 8-10 June 2010, Calgary Canada
• SPE Annual Technical Conference and Exhibition (ATCE), 19-22 Sep 2010, Tuscany Italy

Note: This slide is for the use of the Peer Reviewers only – it is not to be presented as part of your oral or poster presentation. These Supplemental Slides will be included in the copy of your presentation that will be made available to the Reviewers.
ESP Component Overview

- **Centrifugal Pump**
  Creates pressure to produce fluid to surface

- **Fluid Intake**
  Provides path for fluid into pump

- **Submersible Motor**
  Converts Electrical Energy to Rotational Motion

- **Cable and Electrical Connector**
  Delivers Electricity to Motor from Surface

- **Protector**
  Prevents Motor contamination

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Hotline IV addresses the Motor, Protector, and Electrical Connector