Environmental Loss Characterization of an Advanced Stirling Convertor (ASC-E2) Insulation Package using a Mock Heater

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Nicholas A. Schifer
NASA Glenn Research Center
RPT – Thermal Energy Conversion Branch
Net Heat Input Session Presentations

Overview of Heat Addition and Efficiency Predictions for an Advanced Stirling Convertor (ASC)
- Effort improved accuracy of net heat input predictions for ASCs tested at GRC
- Author: Scott Wilson

Environmental Loss Characterization of an ASC Insulation Package using a Mock Heater Head
- Test hardware used as pathfinder for Thermal Standard test materials and methods
- Author: Nick Schifer

Evaluation of Advanced Stirling Convertor Net Heat Input Correlation Methods using a Thermal Standard
- Test hardware used to validate net heat prediction models
- Author: Max Briggs, presented by Nick Schifer

A Computational Methodology for Simulating Thermal Loss Testing of the Advanced Stirling Convertor
- Numerical models validated using test data
- Author: Terry Reid
Why is Net Heat Input Needed?

- Problem: Net Heat Input cannot be measured directly during operation
- Net heat input is a key parameter needed in prediction of efficiency for convertor performance
- Efficiency = Electrical Power Output (Measured) divided by Net Heat Input (Calculated)
- Efficiency is used to compare convertor designs and trade technology advantages for mission planning

Advanced Stirling Radioisotope Generator (ASRG)
Glenn Research Center at Lewis Field

ASC developed by
Department of Energy
and Lockheed Martin

ASC developed by
Sunpower, Inc. & NASA
Glenn Research Center

Advanced Stirling Convertor (ASC)

ASC Heater Head Diagram
What is Net Heat Input?

- Net Heat Input is heat energy required for thermodynamic cycle heat addition + parasitic heat transfer losses inherent to heat engines.

![Diagram showing the flow of heat input to various components such as Heat Source, Insulation Package, Heat Collector Head, and Heater Head Cylinder.]

Net Heat Input = (8) + (7)
Outline

• Problem Statement
• Introduction to the Mock Heater Head
• Role of the Mock Heater Head - Pathfinder
  – Test Configuration
  – Calculations
  – Testing
  – Heat Flow Paths
  – GRCop-84 conducting rod
  – Thermal Imaging
• Conclusions
Problem Statement

During Insulation Loss Testing (Non-operating)

Heat Source 871 °C

Hot End 850 °C

Insulation

During Normal Operation (Operating)

Heat Source 962 °C

Hot End 843 °C

Insulation

Cold Side Adapter Flange (CSAF) 50 °C

Pressure Vessel (PV) 37 °C

CSAF 50 °C

PV 61 °C

Thermal gradients significantly change during operation compared to Insulation Loss Testing
The Mock Heater Head

• Key Mock Heater Head test components include
  – Nickel heater head
  – CSAF (Oxygen free high conductivity copper)
  – Nickel and GRCop-84 conducting rods

• Nickel heater head modified from existing hardware

• Not stand alone hardware
  – Requires heater preload to affix the heater head
  – Requires additional hardware to use the conducting rods

Nickel Heater Head is not bonded to CSAF

Conducting Rod
CSAF
Heater Head

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NASA
Role of the Mock Heater Head

• The Mock Heater Head served as a path finder and proof of concept for the Thermal Standard:
  – Verified the test methodology and configuration
  – Identified instrumentation locations for calculating heat conducted to the cold end
  – Investigated the use of a conducting rod as a representative Stirling cycle and verified GRCOp-84 as a viable material option.
  – Identified features for the heat collector and CSAF
  – Validated use of an IR camera to measure temperatures on the exposed heater components
  – Identified preferred test methods used for characterization
    • Control off of hot-end temperature rather than heater temperature

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Test Configuration

Mock Heater Head Hardware

- Spring loaded preload plate 150 lbs
- Ceramic Preload Stud Cotronics Rescor 902
- Heater Source Nickel, Oxidized, 8 HT Fireods
- Mock Heater Head Nickel
- Insulating Plug Kaowool

HT Fireods

Insulation Housing

Microporous Insulation Zircar Microsil 2

Conducting Rod Nickel or GRCop

CSAF Copper

Conducting Rod Spring loading mech.

Mock Heater Head Instrumentation

- Thermocouple Probe (TP)
- Thermocouple Interface Mount (TS)

0.905 in
1.085 in
0.630 in

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Calculations

• The Mock Heater Head simplified the problem to purely conduction and provided test data for validation of numerical models.

Fourier’s Law: \[ \dot{Q} = KA \frac{\Delta T}{\Delta x} \]

Energy Balance:
\[ \dot{Q}_{\text{env loss}} = \dot{Q}_{\text{heater power}} - (\dot{Q}_{\text{heater head}} + \dot{Q}_{\text{conducing rod}} + \dot{Q}_{\text{HH insulation}}) \]

Validated the use of 1D conduction equations in calculating conduction losses
Testing

ASC-E2 Convertor Test Sequence

<table>
<thead>
<tr>
<th>Test Title</th>
<th>Interface Material</th>
<th>Piston Status</th>
<th>Environmental Loss Calculation Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alumina disk</td>
<td>Alumina disk</td>
<td>Stalled</td>
<td>Conduction calculation</td>
</tr>
<tr>
<td>Thermal barrier</td>
<td>Ceramic paper</td>
<td>Stalled</td>
<td>Conduction calculation</td>
</tr>
<tr>
<td>Nominal operation</td>
<td>Alumina disk</td>
<td>Moving</td>
<td>Empirical model</td>
</tr>
</tbody>
</table>

- Developed the test sequence and data reduction methods
- Identified preferred test methods used for characterization
- Temperature profiles didn’t match as well as expected
Differences in heat flow paths effected the temperature profile.
- Emphasized the need to have accurate heat flow paths in the Thermal Standard.
The GRCop-84 Conducting Rod

GRCop-84
Advantages
- Strength greater than copper
- Thermal Conductivity 80% of copper

Concerns
- Oxidation at elevated temperatures
- TC attachment
- Can it be nickel coated for oxidation protection?

- Verified GRCop-84 as viable material for conducting rod
- Verified nickel plating as viable oxidation protection
Identified and verified use of thermal imaging as a means of defining the thermal profile of the exposed heater components for numerical models.
Conclusions

• The Mock Heater Head served as a path finder and proof of concept in the development of the Thermal Standard as part of the Net Heat Input Investigation
  – Verified the test methodology and configuration
  – Identified instrumentation locations for calculating heat conducted to the cold end
  – Investigated the use of a conducting rod as a representative Stirling cycle and verified GRCop-84 as a viable material option
  – Identified features for the heat collector and CSAF
  – Validated use of an IR camera to measure temperatures on the exposed heater components
  – Identified preferred test methods used for characterization
    • Control off of hot-end temperature rather than heater temperature

Results of the Mock Heater Head drove the design of the Thermal Standard
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Any opinions, findings, conclusions, or recommendations expressed in this article are those of the authors and do not necessarily reflect the views of NASA.