Using Thermoelectric Coolers to Enhance Loop Heat Pipe Performance

Jentung Ku
Dan Butler
Laura Ottenstein
NASA Goddard Space Flight Center
301-286-3130
Jentung.Ku-1@nasa.gov

Gajanana Birur
Jet Propulsion Laboratory

16th Spacecraft Thermal Control Workshop
El Segundo, California, March 9-11, 2005

2005 Aerospace - Ku 3/9/05
Outline

- LHP Operating Temperature
- LHP Start-up Issues
- How TECs Can Enhance LHP Performance
  - Start-up
  - Operating Temperature Control
- Experimental Studies
  - LHP with One Evaporator and One Condenser
  - LHP with Two Evaporators and Two Condensers
- Conclusions
LHP Operating Temperature
One Evaporator and One Condenser

- The LHP operating temperature is governed by the CC temperature.
  - Heat leak from evaporator to CC
  - Subcooling of returning fluid
  - Interaction between CC and ambient

- The CC temperature is a function of
  - Evaporator power
  - Condenser sink temperature
  - Ambient temperature
LHP Operating Temperature Control

- State-of-the-art LHPs use electrical heaters to control the CC temperature.
  - Cold biased
  - Heating only, no active cooling

- TECs provide cooling as well as heating.
  - Cooling mode: expands temperature control to low power region
  - Heating mode: reduces control heater power requirement
LHP Start-up Scenarios

(a) Situation 1

(b) Situation 2

(c) Situation 3

(d) Situation 4
LHP Start-up Issues and TEC Solutions
Situation 4

- **Without TEC (Figure A)**
  - CC temperature rises with evaporator temperature due to heat leaks.
  - Required superheat may never be attained at low powers.
  - Starter heaters have been used to provide a highly concentrated heat flux for local boiling – 20W to 40W is required.

- **With TEC (Figures B and C)**
  - TEC can maintain a constant CC temperature to achieve the required superheat, resulting in a successful start-up.
  - TEC can also cool the CC to create the required superheat.
  - Starter heaters can be eliminated.

---

**Figure A**

**Figure B**

**Figure C**

---

2005 Aerospace -Ku 3/9/05
LHP Start-up Issues and TEC Solutions  
Situation 2

- Without TEC (Figure A)
  - Flow circulation starts after evaporator temperature rises above CC set point.
  - However the CC temperature may rise with evaporator temperature due to heat leaks.
  - Net heat load to evaporator decreases, leading to ever-increasing CC temperature, possibly violating the instrument maximum allowable temperature.

- With TEC (Figures B and C)
  - TEC can maintain a constant CC temperature, ensuring successful start-up and attainment of a steady state.
  - TEC can also cool the CC to start the loop.
  - Starter heaters can be eliminated.

---

**Figure A**
![Graph showing temperature changes over time](attachment:image1.png)

**Figure B**
![Graph showing temperature changes over time](attachment:image2.png)

**Figure C**
![Graph showing temperature changes over time](attachment:image3.png)
Experimental Studies with Two LHPs

- **Objectives**
  - Demonstrate that TECs can be used to enhance LHP start-up success
  - Demonstrate that TECs can be used to control the CC temperature with small control powers

- **ThermaCore Miniature LHP**
  - Single evaporator and single condenser
  - Evaporator size: 7mm O.D. x 50mm L
  - Tests performed with 0g, 117g, and 350g of thermal masses attached to the evaporator

- **MLHP**
  - Two evaporators and two condensers
  - Evaporator size: 15mm O.D. x 76mm L
  - Tests performed with 500 g thermal mass attached to each evaporator
# Design Summary of Thermacore Miniature LHP

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporator</td>
<td>Aluminum Shell</td>
</tr>
<tr>
<td></td>
<td>7 mm O.D. x 51 mm L</td>
</tr>
<tr>
<td>Primary Wick</td>
<td>SS, 5.6 mm O.D. x 2.4 mm I.D</td>
</tr>
<tr>
<td></td>
<td>1.2 μm pore size, 1.0 x 10^-14 m^2 permeability</td>
</tr>
<tr>
<td>Secondary Wick</td>
<td>SS screen, 400 x 400 mesh</td>
</tr>
<tr>
<td>Compensation Chamber</td>
<td>SS</td>
</tr>
<tr>
<td></td>
<td>9.52 mm O.D. x 25.5 mm L</td>
</tr>
<tr>
<td>Vapor Line</td>
<td>SS, 1.59 mm O.D. x 560 mm L</td>
</tr>
<tr>
<td>Liquid Line</td>
<td>SS, 1.59 mm O.D. x 635 mm L</td>
</tr>
<tr>
<td>Condenser</td>
<td>Aluminum</td>
</tr>
<tr>
<td></td>
<td>2.39 mm O.D. x 200 mm L</td>
</tr>
<tr>
<td>Working Fluid</td>
<td>Ammonia, 1.5 grams</td>
</tr>
<tr>
<td>Total mass</td>
<td>79 grams</td>
</tr>
</tbody>
</table>
Pictures of Thermacore Miniature LHP
One Evaporator and One Condenser

Aluminum Plate
50mm x 75 mm

Condenser Line
2.39 mm OD
200 mm L

Evaporator
7 mm OD

Condenser

Vapor Line
1.59 mm OD
560 mm L

Compensation
Chamber 9.52 mm
OD

TEC Saddle

Liquid Line
1.59 mm OD
635 mm L

Fill Tube

Copper Strap

Slot for TEC

Aluminum Saddle

2005 Aerospace - Ku 3/9/06
Schematic of Thermacore Miniature LHP
# MLHP Design Parameters

**Two Evaporators and Two Condensers**

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporator (2)</td>
<td>Aluminum, 13mm O.D. x 76.2mm L each</td>
</tr>
<tr>
<td>Primary wick</td>
<td>Nickel, 0.6 μm pore radius, 60% porosity, 1.4x 10^-14 m^2 permeability</td>
</tr>
<tr>
<td>Primary wick</td>
<td>Titanium, 3 μm pore radius, 60% porosity, 1.0x 10^-14 m^2 permeability</td>
</tr>
<tr>
<td>CC (2)</td>
<td>Stainless steel, 18mm O.D. x 61mm L, 18cc each</td>
</tr>
<tr>
<td>Vapor line</td>
<td>Stainless steel, 2.38mm O.D. x 1200mm L</td>
</tr>
<tr>
<td>Liquid line</td>
<td>Stainless steel, 1.59mm O.D. x 1200mm L</td>
</tr>
<tr>
<td>Condenser (2)</td>
<td>Stainless steel, 2.38mm O.D. x 760mm L each</td>
</tr>
<tr>
<td>Flow regulator</td>
<td>Polyethylene wick, 40 μm pores</td>
</tr>
<tr>
<td>Working fluid</td>
<td>Anhydrous ammonia, 15.5 grams</td>
</tr>
</tbody>
</table>
MLHP Picture
(with Thermal Masses and TECs)
MLHP Schematic
Two Evaporators and Two Condensers
TEC Connections

Copper Strap

TEC

CC

Evaporator
MLHP Test Results - Star-up
(5W/5W, 273K/273K, Horizontal, No TEC Control)

- In most cases, MLHP start successfully without using TECs
- There were a few cases where TECs were used to achieve successful start-ups.
MLHP Test Results - Star-up
(5W/5W, 273K/273K, Condensers Slightly above Evaporators)

ST8 LHP 2/19/2004

- CC2 could not reach a steady temperature and E2 was drying out
- At 11:45, TEC2 was turned on and set at 303K. Loop operated steadily afterwards.
MLHP Test Results – Starts and Operates on Parasitics

MLHP-ST8  7/30/2004

Temperature (K)

Liq Line (29)
Vap Line (21)
Thermal Mass (71)
CC1 (89)

CC1 and CC2:  No Control/ 283K/278K/275K/No Control

2005 Aerospace - Ku 3/9/05
MLHP Test Results – Starts and Operates on Parasitics

MLHP - ST8  7/30/2004

<table>
<thead>
<tr>
<th>Time</th>
<th>13:30</th>
<th>14:00</th>
<th>14:30</th>
<th>15:00</th>
<th>15:30</th>
<th>16:00</th>
<th>16:30</th>
<th>17:00</th>
<th>17:30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (K)</td>
<td>300</td>
<td>295</td>
<td>290</td>
<td>285</td>
<td>280</td>
<td>275</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MLHP Test Results – Temperature Control
(CC1, CC2, or CC1/CC2 Control Set at 303K, E1/E2 Power Varied)

ST8 LHP 3/3/2004

- Loop operated stably at 303K
  - Alternate CC1 and/or CC2 control at 303K
  - Uneven heat loads at 100W/5W and 5W/100W; rapid power change
  - Uneven sink temperatures; rapid sink cycle between 253K and 293K

2005 Aerospace -Ku 3/9/05
MLHP Test Results – Temperature Control
(C1/C2 Sinks = 283K/283K)

ST8 July 2, 2004

- 9:40 – 10:37 No active control of CCs
- 10:37 – 11:48 CC1 and CC2 controlled at 295K
- 11:48 – 13:42 No active control of CCs
- TECs allowed the MLHP to operate at 295K
## MLHP TEC Control Heater Power
### 303K CC2 Set Point

<table>
<thead>
<tr>
<th>E2 Power (W)</th>
<th>TEC2 Power (W) @263K Sink</th>
<th>TEC2 Power (W) @273K Sink</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>40</td>
<td>0.8</td>
<td>0.6</td>
</tr>
<tr>
<td>60</td>
<td>2.0</td>
<td>1.5</td>
</tr>
<tr>
<td>80</td>
<td>3.2</td>
<td>2.4</td>
</tr>
<tr>
<td>100</td>
<td>3.5</td>
<td>2.8</td>
</tr>
<tr>
<td>120</td>
<td>3.8</td>
<td>2.6</td>
</tr>
</tbody>
</table>
Summary and Conclusions

- TECs can be used to enhance LHP start-up success.
  - Maintain a constant CC set point temperature
  - Lower the CC temperature
  - May eliminate the need for starter heaters

- TECs can be used to broaden the range for LHP operating temperature control.
  - Cooling mode: maintain CC temperature at low powers
  - Heating mode: reduce the required control heater power

- Experimental results with one-evaporator and one-condenser LHP
  - TEC can maintain the operating temperature within ±0.3K between heat loads of 0.5W and 100W.
  - TEC requires less than 1W over the entire power range.

- Experimental results with two-evaporator and two-condenser LHP
  - TEC can maintain the operating temperature within ±0.3K between heat loads of 5W and 120W.
  - TEC requires less than 4W over the power range.
  - TEC enables LHP to start and operate with parasitic heat gains alone (no power to the evaporators).