Heat pipe applied indirect cooling system for high voltage battery packs in PHEVs

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Outline

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- Importance of thermal management on battery life
- Battery cooling system requirements
- Types of cooling systems for high voltage battery packs

Ⅱ. Indirect Cooling Systems
- Heat pipe applied indirect cooling systems
- Structure of indirect cooling systems
- Cooling performance

Ⅲ. Summary
Introduction

I. Importance of thermal management on battery life

Temperature affects battery:

- Operation of the electrochemical system
- Round trip efficiency
- Charge acceptance
- Power and energy availability
- Safety and reliability
- Life and life-cycle cost

Battery temperature affects vehicle performance, reliability, safety and life cycle
Introduction

Temperature Impacts Battery Sizing & Life and Cost

Power Limits

Sluggish Electrochemistry

Rated Power

Degradation

Desired Operating Temperature

Power limited to minimize T increase and degradation

Dictates power capability

Also limits the electric driving range

Power and energy fade rates determine the original battery size

Kandler Smith, NREL Milestone Report, 2008
Introduction

Ⅱ. Battery cooling system requirements

- Compact
- Lightweight
- Easily packaged
- Reliable
- Low-cost
- Low parasitic power
- Optimum temperature range
- Small temperature variation
# Introduction

## III. Types of cooling systems for high voltage battery packs

<table>
<thead>
<tr>
<th>Type</th>
<th>Battery cooling system</th>
<th>Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cabin air cooling</td>
<td><img src="cabin_diagram.png" alt="Diagram" /></td>
<td>KIA SOUL EV</td>
</tr>
<tr>
<td>Direct refrigerant-based cooling</td>
<td><img src="direct_diagram.png" alt="Diagram" /></td>
<td>Mercedes Benz S400 HEV</td>
</tr>
<tr>
<td>Chiller and heat sink in battery</td>
<td><img src="chiller_diagram.png" alt="Diagram" /></td>
<td>GM VOLT PHEV</td>
</tr>
</tbody>
</table>
Indirect cooling systems

I. Heat pipe applied indirect cooling systems

<table>
<thead>
<tr>
<th>Conventional direct air cooling</th>
<th>Indirect air cooling</th>
<th>Indirect water cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Conventional direct air cooling" /></td>
<td><img src="image2" alt="Indirect air cooling" /></td>
<td><img src="image3" alt="Indirect water cooling" /></td>
</tr>
<tr>
<td>Air flow direct convection</td>
<td>Air flow indirect convection via heat sink</td>
<td>Liquid flow indirect convection via liquid channel</td>
</tr>
</tbody>
</table>

※ Thermal conductivity of heat pipe: 4000 W/mK (Supported by INNO TM)
## Indirect cooling systems

### II. Structure of indirect cooling systems

**Battery Pack**

- Battery: Li-ion Battery (Pouch type)
- Battery Capacity: 29Ah (64 cell)
- Nominal Voltage: 180V
- Energy: 3.48 kWh

※ Compact battery pack with high volume energy density can be designed

### Indirect Air Cooling System

- Air In
- Heat Sink & Heat Pipe
- Battery Module (8 cell)
- Air Out

### Indirect Liquid Cooling System

- Liquid Cooling Channel
- Liquid In
- Liquid Out
- Heat Pipe
- Battery Module (8 cell)
Indirect cooling systems

III. Cooling performance

**Conditions**

- Environmental temperature: 45 °C
- Inlet air or liquid temperature: 35 °C
- Input current: ± 70 A (charge/discharge)
- Air flow rate: 80 m³/hour
- Liquid flow rate: 6 ℓ/min

<table>
<thead>
<tr>
<th>Cooling system</th>
<th>$T_{\text{max}}$ (°C)</th>
<th>$\Delta T$ (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct air</td>
<td>≤ 50</td>
<td>≤ 5</td>
</tr>
<tr>
<td>Indirect air</td>
<td>48.7</td>
<td>2.3</td>
</tr>
<tr>
<td>Indirect liquid</td>
<td>42.7</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Saturation Temperature of Battery pack

Temperature Variation ($T_{\text{max}} - T_{\text{min}}$)
Summary

I. The heat pipe applied cooling systems are developed for reducing volume (raising energy density) by removing the conventional air channel (air gap).

II. The new indirect (air/liquid) cooling systems show better cooling performance comparing to the direct air cooling one in the maximum temperature and temperature variation.

III. Conducting battery pack heating performance of indirect liquid cooling systems will be carried out in the near future.