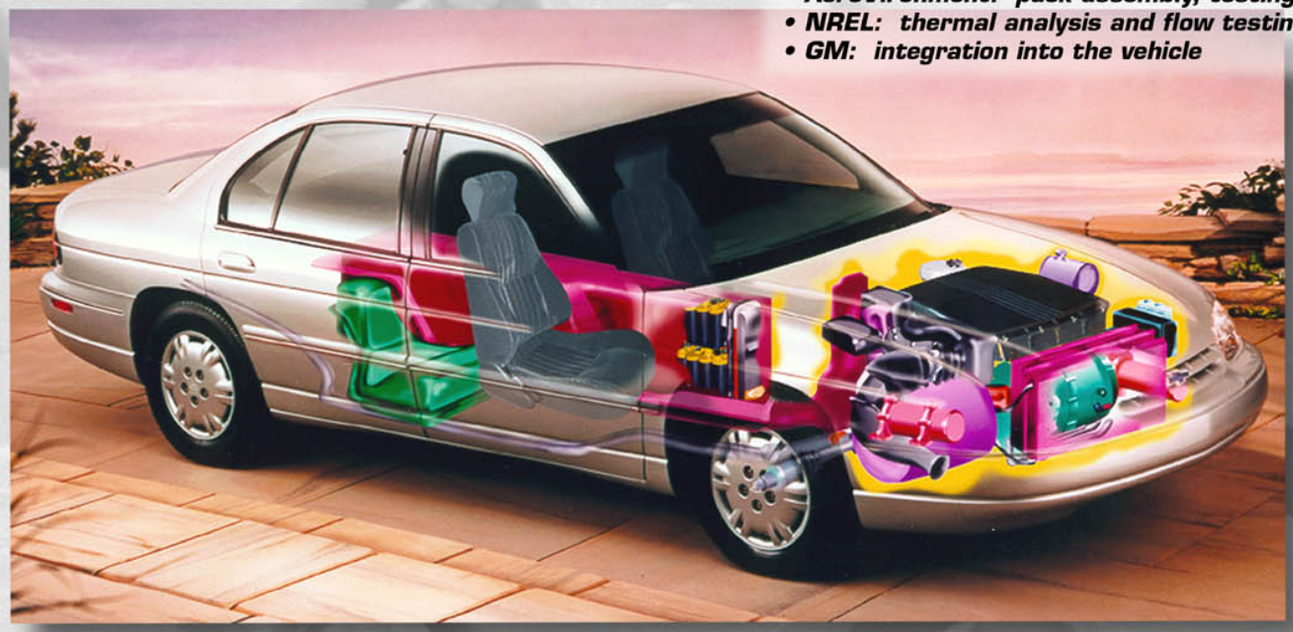
General Motors and U.S. Department of Energy collaborated on developing a series hybrid electric vehicle.

- Conversion Vehicle: Chevrolet Lumina sedan
- Hybrid Power Unit: a 40-kW Stirling engine
- Battery Pack: a 100-kW lead acid battery pack

Optima, AeroVironment, and NREL collaborated on the battery pack for GM.

- Optima: module development and production
- AeroVironment: pack assembly, testing, and monitoring
- NREL: thermal analysis and flow testing
- GM: integration into the vehicle



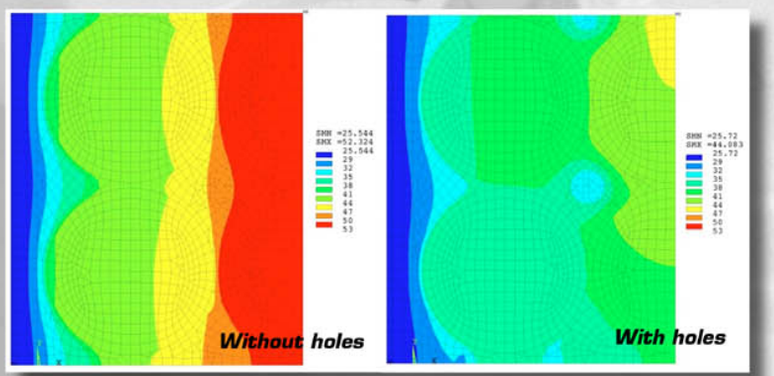
For desired vehicle performance, battery pack thermal management systems must . . .

- Maintain modules within their optimum operating temperature range
- Maintain even temperature distribution among modules
- Meet the inherent constraints posed by the vehicle

Objective

To develop a thermal management system for operating the pack evenly within the desired optimum temperature range.

- Air as the cooling medium
- Ambient operating temperature: 15°- 30°C
- Desired operating range: 35°- 45°C



Thermal analysis showed that adding cooling holes to an Optima module improves its thermal performance.

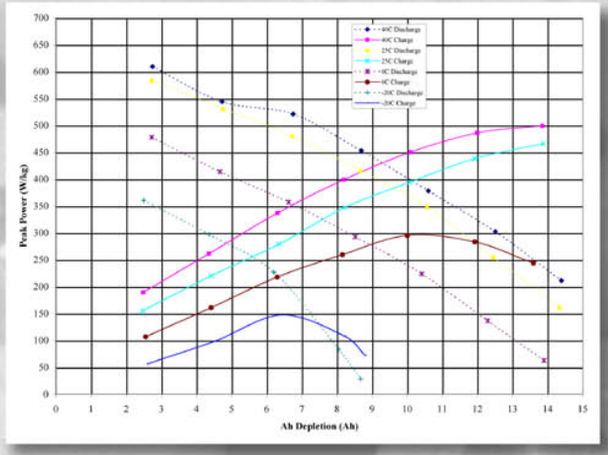
Approach

- Analyze the module's thermal performance
- Investigate performance of various thermal management systems
- Develop/assemble pack and its thermal management system
- Test and refine the thermal management system
- Assess electrical performance
- Evaluate thermal and airflow performance

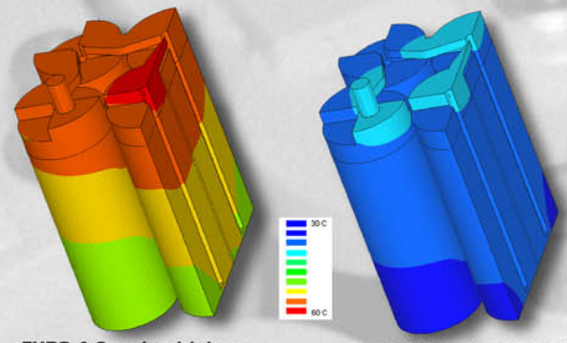
- Lead acid
- 16.5 Ahr
- 12 V

The latest Optima HEV modules incorporate cooling holes and a thermal well for measuring internal module temperature.

Results



Optima battery performance increases with temperature.

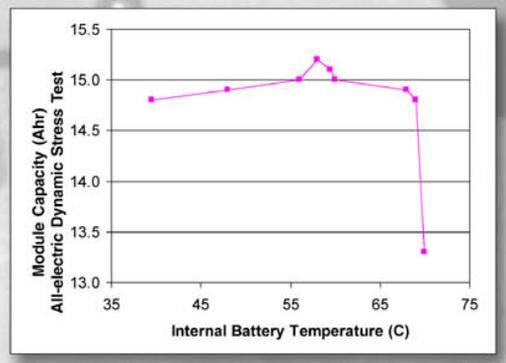


FUDS 1.3 cycle with heat generation of 32.9 W/module

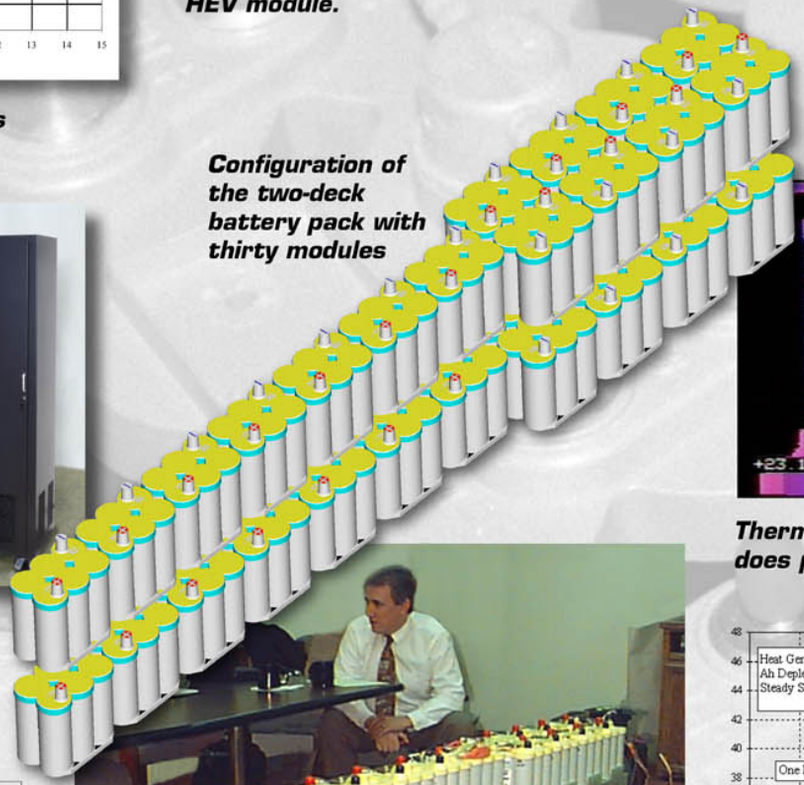
FUDS 1.0 cycle with heat generation of 10 W/module

We used finite element analysis to obtain 3-D steady-state temperature distribution in the HEV module.

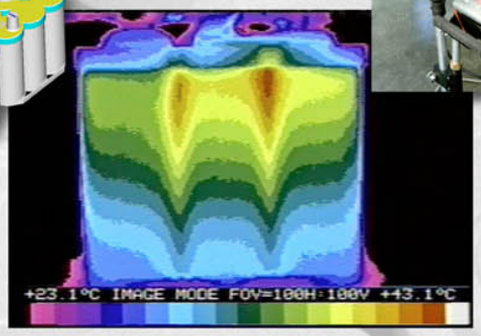
Damage may occur if the Optima module's internal temperature exceeds 65°C.



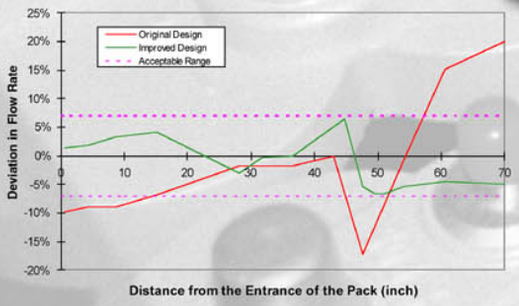
We used the NREL calorimeter/cycler to obtain heat generation data from batteries under various cycles.



Configuration of the two-deck battery pack with thirty modules

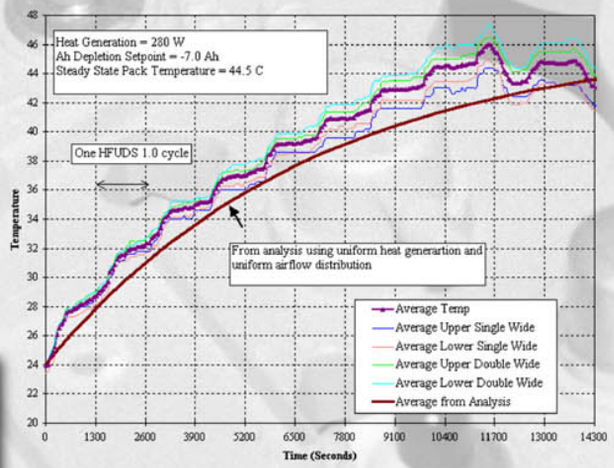


Thermal imaging shows that the model does predict trends in thermal behavior.



Testing and incorporating new designs improved the flow uniformity with the same fan power.

Battery pack assembled by AeroVironment for the GM series HEV



Thermal model predicted battery pack thermal performance under hybrid FUDS cycling reasonably well.

Conclusions

We conducted analysis and testing to design an air-cooled thermal management system for a battery pack of the GM/DOE series HEV.

We found that the thermal management system performed well, except under high thermal loads of FUDS 1.3.

We believe that for very hot or cold climates, the system needs to be modified to include active heating or cooling components.

Acknowledgment - This work was sponsored by the U.S. Department of Energy as part of the cost-shared Hybrid Vehicle Propulsion Systems Program with GM.