Thermal Management for Electric Cars

Active vs. Passive Systems

Thermal management of batteries in electric vehicles (EVs) and hybrid electric vehicles (HEVs) is essential for effective operation in all climates. This has been recognized in the design of battery modules and packs for pre-production prototype or production EVs and HEVs. Designs are evolving and various issues are being addressed. There are trade-offs between performance, functionality, volume, mass, cost, maintenance, and safety.

There are many things that need careful consideration in the design and management of batteries used in hybrid or electric vehicles. However, one of the principal challenges facing the EV market – battery thermal management (BTM) – is the subject of an on-going debate as to the most effective architecture.

Key to optimizing performance and safety of the current generation Li-ion batteries is the maintenance of the temperature across all the cells. Battery temperature influences the availability of discharge power (for start up and acceleration) as well as energy and charge acceptance during energy recovery from regenerative braking and charging.

The maximum heat build-up from a battery pack under load, dictates the size and design of the cooling system. The heat generation (due to electrochemical enthalpy change and electrical resistive heating) depends on the chemistry type, construction, ambient temperature, state of charge, and charge/discharge profile.

Therefore, the goal of a thermal management system is to deliver a battery pack that functions at an optimum average temperature with even temperature distribution across all cells. However, the thermal management system must also be compact, lightweight, low cost, easily packaged, and compatible with the location in the vehicle. In addition, it must be reliable, and easily accessible for maintenance, with low parasitic power losses whilst allowing the pack to operate under a wide range of climatic conditions (very cold to very hot).

Whilst all parties agree on the requirements, there's intense debate around which system is most effective: Passive (i.e., only the ambient environment is used), or active (i.e., a built-in source provides heating and/or cooling at cold or hot temperatures). To add to the debate thermal management systems may use air or liquid for heating/cooling/ventilation: Or alternatively phase change materials can be used for insulation and thermal storage.

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Passive Thermal Management

Because of cost, mass, and space considerations many EVs, rely on passive thermal management to control the temperature of the batteries. Early HEVs also used passive ambient air-cooling. A development of this concept used in several HEVs (Honda Insight and Toyota Prius) uses cabin air for cooling/heating of the pack. Although the ambient air is heated or cooled by the vehicle's air conditioning or heating system, it is still considered to be a passive system.

However in more demanding ambient conditions this form of passive BTM has limitations. This was well illustrated when Nissan Leaf owners in Arizona experienced severe degradation of battery capacity because of high ambient temperatures.

During controlled tests, a group of Nissan Leaf owners measured the range of 12 used vehicles, and compared these to a new car's range. The data indicated a significant loss of range. Responding to this data Nissan confirmed that, normally, battery capacity will decrease 30 percent in ten years, but importantly, noted that exposure to high temperatures could accelerate degradation. The way a cell degrades is generally a capacity loss, and the auto industry has defined the end of useful life as when the whole battery pack capacity has dropped to 80% of the "as-new" capacity. What this means, practically, is that the vehicle range will decrease over the lifetime – the vehicle will still be usable, but the operating range will have decreased.

It's clear that traditional passive BTM is not up to the job under extreme conditions; but it's also well documented that tight control over operating temperatures can significantly extend battery life.

Using phase change composites in passive BTM

Applying technology developed and patented at the Illinois Institute of Technology, Chicago-based firm AllCell Technologies has developed a solution to this passive thermal management challenge that is simple and lightweight, whilst remaining low cost. Using a phase change material (typically wax) combined with graphite, AllCell have produced a composite material that does away with the moving parts and parasitic energy losses of active BTM systems.

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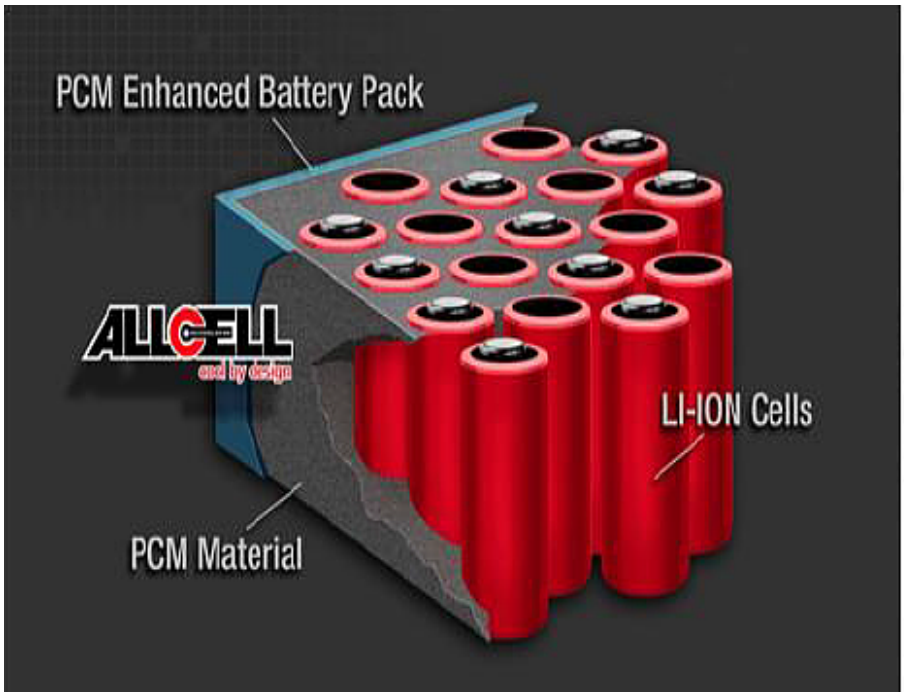
When integrated into a lithium-ion battery pack, AllCell's phase change composite (PCC) provides three key benefits:

- Absorbs environmental heat
- Extended life cycle
- Eliminates thermal runaway

The AllCell BTMS places the lithium-ion cells in the battery pack in direct contact with the PCC. As the pack heats up, the graphite acts as a thermal conductor and distributes the heat evenly throughout the pack, avoiding hot spots and ensuring thermal uniformity. Once the PCC reaches melting point, all excess thermal energy drives the melting process rather than increasing cell temperature.



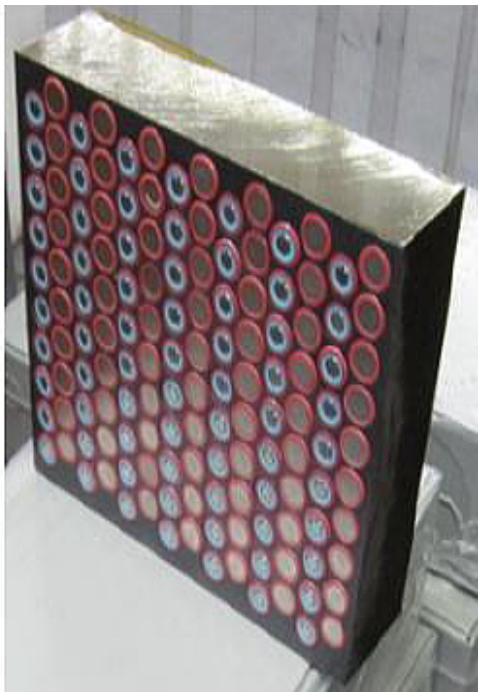


Image: AllCell Technologies

Thus a temperature ceiling is created by the phase change of the PCC until all of the material is melted (see graph below). Even though the PCC is "melting" the composite material remains solid, thereby preventing leakage.

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By considering each product's lithium-ion chemistry and duty cycle when selecting different raw materials and system designs, the maximum temperature in each pack is optimized for performance and battery life. While the addition of PCM probably won't eliminate the need for active cooling altogether, it could simplify the system in an active/ passive hybrid BTMS. During high discharge rates (heavy acceleration) the heat generated increases exponentially. Under these conditions the PCM will absorb the temperature spikes, thereby allowing for the size of the active system to be designed around the average thermal load rather than the peak – potentially replacing flowing liquid between each cell with a couple of fans or a simpler liquid loop.

Due to the impact of BTM on battery life and performance many manufacturers have chosen active BTM, despite the increased cost and complexity: Active BTM accounts for approximately 10-20 percent of the overall cost of the battery pack.

Active battery thermal management

The safe power density of a battery cell in charge or discharge modes changes as a function of SoC - state of charge, temperature and SoH - state of health. To maximise the performance of the battery cells, the BMS needs to gather sufficient information about the battery cell characteristics and condition as a function of these parameters so that the individual cells that make up the battery can be managed. This not only prolongs cell life, but also allows more of the theoretical energy held in the cell to be safely used. Whereas this seems logical, it presents a number of technical challenges when applied to automotive traction batteries: Typically a battery could consist of 100 cells and the control circuits required to move energy between these cells during charging would require several meters of cabling.

In order to accurately micro-manage individual cells Robert Bosch and partners, Pro Design Electronic GmbH, University of Applied Sciences and Arts (Hannover) and the Karlsruhe Institute of Technology (KIT) have launched a new €4.3-million project to improve battery performance in hybrid and electric vehicles using intelligent battery management.

Dr. Jens Strobel, coordinator of the project at Robert Bosch GmbH, explained that the objective was to design a system that constantly monitors and controls each battery cell individually.
The technical basis of the IntLilon project is an innovative method that uses powerline communications systems to efficiently control and monitor each of the up to 100 cells found in a battery pack. This powerline system will eliminate the need for the costly extra data-transmission wiring that has been necessary in all the battery systems used to date.

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Many manufacturers are studying integrated thermal energy management in EV's and HEV's: These systems seek to manage battery temperatures, cabin comfort levels as well as engine temperatures in hybrid vehicles.

Integrated thermal management

Valeo, a global expert in automotive thermal management, has developed a completely new architecture, with three fluid loops operating at different temperatures. The main water loop cools the drivetrain and heats the cabin, the refrigerant loop cools the cabin and the third loop, also a water loop, provides thermal management for the battery.

This global architecture optimizes energy flows in order to guarantee both the reliability of the drivetrain components and maximize the range. The main water loop cools the driveline and heats the cabin. This hot loop uses equipment that is standard on internal combustion engine vehicles. The water radiator is adapted for a low coolant-temperature flow, with a fan located in front of it engaging when temperatures increase. The fan has been designed for greater durability, since it is required to operate for extended periods during battery charge. Specially shaped blades are designed for totally silent operation, allowing the vehicle to be charged at night.

In this architecture, the third loop ensures battery thermal control by circulating conditioned water through the battery casing. Energy for heating is drawn from the main loop, and for cooling from the refrigerant loop.

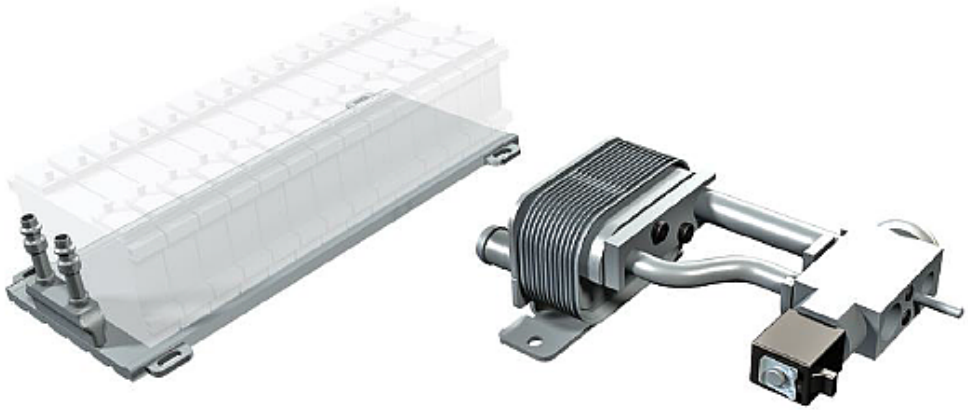

Image: Valeo

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Depending on the automaker's requirements and needs in terms of efficiency, cost and standardization, Valeo also offers alternative solutions such as cooling by air circulation, direct cooling, or a thermoelectric reversible hot-cold system.

With active BTMS costing significantly more than passive systems it's not surprising to see these fitted to high-end production vehicles such as the Mercedes S class HEV:

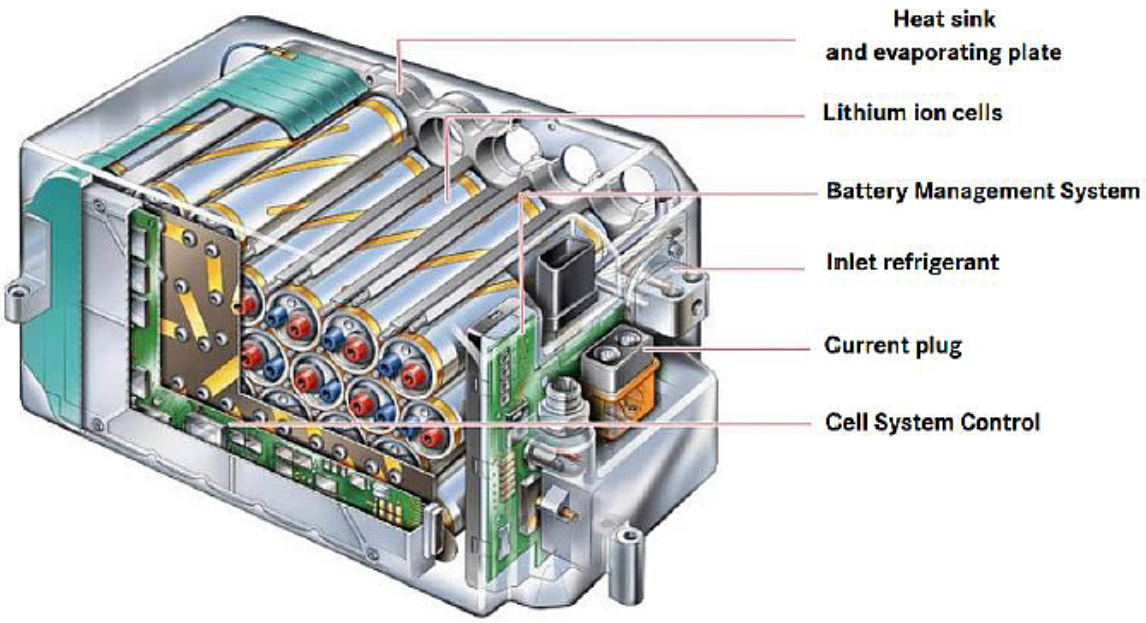

Image: HEV-Battery , S-Class S400 Hybrid, Dr. Florence Michel, Daimler AG

But what is even more important is that manufacturers such as Kia have chosen active BTM as the management architecture in lower cost small cars.

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Active BTMS in low cost vehicles

The Kia Soul's power pack, comprising 192 lithium-ion polymer battery cells in eight modules, incorporates state-of-the-art active thermal control technology to maintain individual cells at optimum temperature, delivering a total power output of 27 kWh.

Kia have chosen Lithium-ion polymer technology to enhance the active BTM. This type of battery uses a 'pouch film' as packing material as opposed to lithium-ion batteries which use a metal can for packaging. The advantages of a lithium-ion polymer battery (compared to normal lithium-ion batteries) include: greater efficiency due to the simple cell structure (fewer parts), lower costs, increased safety and reliability (due to better thermal diffusion and internal pressure control) and flexibility in manufacturing a variety of capacities and shapes.

Using a unique electrolyte additive the Soul EV battery can function over a wide operating temperature range thereby reducing the impact of temperature on the driving range.
To improve cold weather battery performance the Soul EV features a battery heating system, which warms-up the battery while the car is plugged into the grid, prior to use. This initial conditioning helps maintain optimum battery performance regardless of the external temperature.

The advent of phase change composite materials could very well be the bridge that settles the debate over the superiority of passive versus active BTM in favor of a hybrid system: With the winner being EV and HEV technology advancement in closing the range and performance gap to internal combustion engine powered vehicles.

Sources:

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- Thermal management of a li-ion battery in a hybrid passenger car – Dr. Florence Michel, Daimler AG