



SURFACE VEHICLE INFORMATION REPORT

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Battery Thermal Management

RATIONALE

This Information Report is a survey of various types of systems used in automotive and commercial vehicles for the thermal management of batteries.

1. SCOPE

This document surveys the systems used for thermal management of batteries in vehicles. Battery thermal management is important for battery performance and cycle life. The document also includes a summary of design considerations for battery thermal management and a glossary of terms.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J1004 Glossary of Engine Cooling System Terms

SAE J1715/2 Battery Terminology

3. INTRODUCTION

Electric Vehicle (EV), Hybrid Electric Vehicle (HEV), Plug-in Hybrid Electric Vehicle (PHEV), and Fuel Cell Electric Vehicle (FCV) traction batteries are characterized by high energy density (Wh/kg) and high power density (W/kg). The most popular types of batteries for EV, HEV, PHEV, and FCV are Nickel-Metal Hydride (NiMH) and Lithium Ion (Li-Ion) batteries. Applications of NiMH batteries have been seen with commercial HEVs whereas Li-Ion batteries are frequently used with PHEVs, EVs, and FCV. Higher energy density of the Li-Ion batteries is particularly attractive for enabling longer electric driving range. Table 1 provides a quick comparison with the standard Lead Acid (PbA) battery included as a baseline technology.

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Table 1 - Typical characteristics of common automotive batteries

Battery Type	Energy Density (Wh/kg)	Charging Efficiency (%)	Charging Cycles
Lead Acid	30-40	70-75%	300-500
NiMH	30-80	60-70%	>1000
Li-Ion	100-200	80 - 90%	>1000

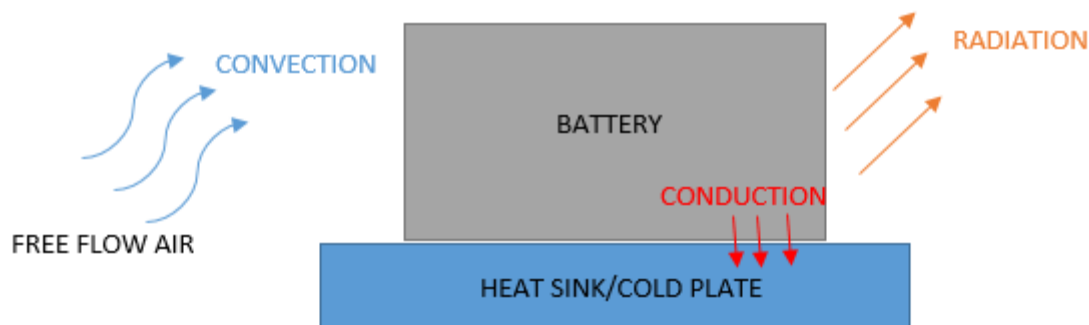
For optimal performance of Li-Ion, NiMH, and PbA batteries, battery cells need to be maintained at their recommended temperature. It has been recognized that batteries operate optimally near 25 °C ambient, almost exactly the preferred comfort conditions for vehicle occupants.

Batteries increase in temperature during operation and can be affected by environment temperature conditions. Low temperatures can cause a loss of battery capacity, which leads to reduced driving range and lower charge / discharge limits. As much as 50% range loss may be observed in ambient temperatures under -20 °C. High operating temperatures are detrimental to battery durability and may cause the vehicle to stop working or even thermal run-away reactions. The temperature difference between the cells within a battery pack needs to be minimized in order to maintain a balanced operation of the battery and avoid premature aging of the cells exposed to higher temperatures.

A Battery Thermal Management System functions to keep the battery pack working at a proper temperature range. The different architectures of a Battery Thermal Management System are described in the following paragraphs.

4. PASSIVE AIR COOLING AND HEATING SYSTEMS

The fundamental difference between active and passive thermal management systems is whether power is required to achieve thermal energy flow. Active thermal management requires a component that consumes energy input to achieve heat transfer to or from the battery. Passive systems rely solely on “natural convection” of the cooling or heating fluid (liquid or air) moving slowly due to temperature gradients to achieve heat transfer. Passive systems provide heat transfer to/from the battery using three mechanisms: Conduction, Convection, and Radiation (Figure 1). Of these three mechanisms, radiation plays a minimal role in heat transfer. Conduction and convection account for almost all of the heat transfer. Passive convection can be transformed to active convection by using a fan to move the air over the battery.

**Figure 1 - Battery heat transfer types**

Many considerations need to be taken into account when using a passive system. Heat always transfers from hot to cold. Other objects, such as an engine, may radiate more heat than the battery. Under hood or under body environmental temperature may be warmer than the battery itself. Airflow from the vehicle's engine fan may heat up the battery with convection. Strategically placing the battery out of other heat generating environments will improve the effectiveness of passive systems. The vehicle may also include designs to increase outside airflow over the heat sink and battery.

Batteries may be placed inside the cabin to take advantage of the cabin HVAC system; batteries and humans like the same general temperature. However, battery off-gassing needs to be taken into consideration for batteries located inside the cabin.

Passive systems are inexpensive to implement due to the low number of components required as well as low complexity in design. In terms of packaging, passive systems do not require too much space or energy from vehicle (no electrical energy). These systems can be used if the battery does not operate in extremely high temperature environments. It is best if these systems are used for batteries that are mostly in a charge-sustaining mode. Batteries will generate extra heat in a charge depleting or charge accepting mode that will challenge the capacity of passive systems.

In general, a passive cooling/heating system is strongly influenced by the environmental condition it operates in. The steady state thermal response will always be affected by the temperature of the environment.

4.1 Application

Passive systems are applicable to battery systems with typical cell heat rejections up to 5 W/cell.

5. ACTIVE AIR COOLING AND HEATING SYSTEMS

Active Air Cooling and Heating Systems (AACHS) uses air as a heat transfer medium to control and distribute the temperature of a battery pack. The system typically uses a blower or fan to move air through the battery (usually using air ducts).

Forced air cooling/heating of a battery system is often preferred for HEVs, sometimes PHEVs, and occasionally EVs. This type of system is typically less complicated to apply due to the lowered requirement for air-tightness of the battery pack as compared with what is required by a liquid system. Battery pack design is also simplified, as there are reduced concerns for short-circuiting within the battery pack that may be caused by liquid, as air is normally an insulator. Equally significant, battery cooling/heating with forced air is very cost competitive because, in addition to simplified battery design, the external supporting components are few and inexpensive.

5.1 Classification of Air Cooled/Heated Systems

Air based battery thermal management systems may be classified into either Direct or Indirect AACHS. Figure 2 shows a Direct AACHS whereby conditioned air is forced through the flow paths formed between battery cells (see more details of manifold type flow paths in Section 9.3 of this document). Conditioned air streams come into direct contact with the battery cells to transfer heat and ensure the cell temperatures are maintained within the required range to ensure safety, efficiency and durability.

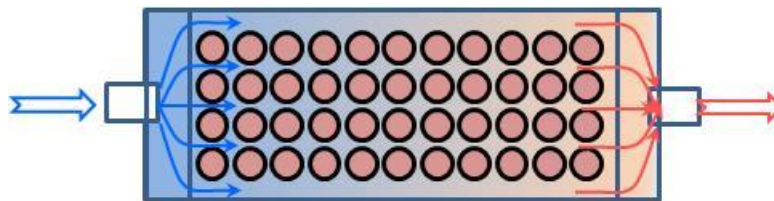


Figure 2 - Direct AACHS

As an indirect system, the system shown in Figure 3 provides battery thermal management through the plates that separate the battery modules. The plates are cooled/heated at one end by the convection of conditioned air, and act as the extended heat transfer surfaces for the battery cells. In comparison with the Direct AACHS, applications of the Indirect AACHS are generally not as extensive, possibly because of the thermally inefficient combination of air convective cooling/heating in the vehicle environment and the heat conduction through the plates. Direct AACHS will be discussed in the following paragraphs, but Indirect AACHS can also be used.

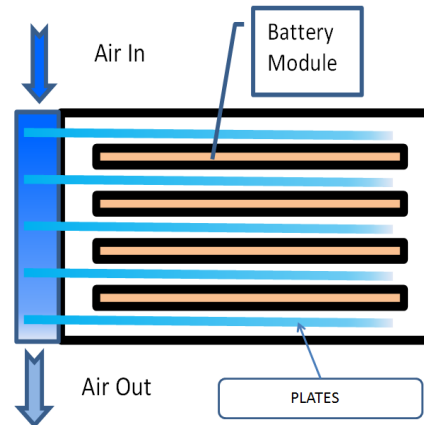


Figure 3 - Indirect AACHS

5.2 Direct AACHS Architectures

AACHS systems may also be classified according to how the air is conditioned. It is an Ambient Air AACHS if the air stream comes from the outside ambient unconditioned (Figure 4) and a Cabin Air AACHS if the air stream comes from inside the cabin, conditioned by the climate control system (Figure 5).

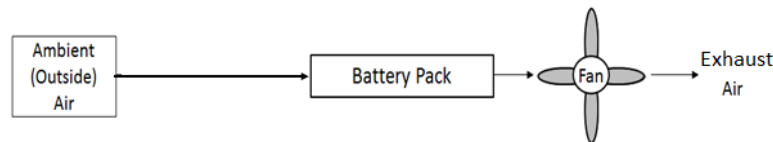


Figure 4 - Ambient air AACHS

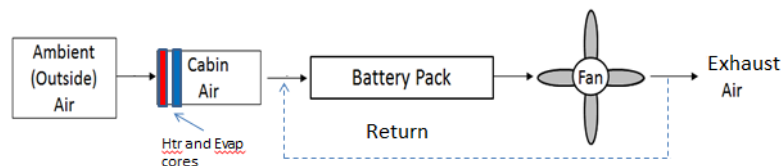


Figure 5 - Cabin air AACHS

Figure 6 shows a typical Cabin Air Direct AACHS architecture. The cabin is conditioned by the HVAC system. The typical cabin temperature is in the range of 22-26 °C for passenger comfort. Normally, vehicles with hybrid or electric powertrains come with an automatic climate control system to maintain the cabin temperature automatically starting from the initially soaked state to the final desired cabin temperature. The calibration and operation of the automatic climate control system ensure that there is always some portion of fresh outside air, injected into the cabin. In addition to normal climate control considerations, the percentage of outside air is provisioned to meet the airflow requirement of the battery pack. From the air balance of the cabin, the outside air stream must be exhausted through the body exhaust while the recirculated air remains in the cabin. The cabin air is fed through the battery pack to provide battery cooling/heating. The outlet air from the battery pack is exhausted or in some cases, some air is recirculated back into the battery pack.

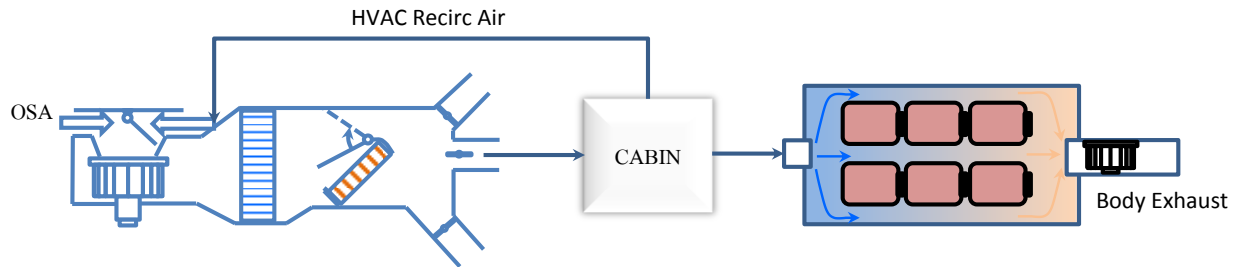


Figure 6 - Cabin air direct AACHS architecture

Figure 7 shows a battery pack design using Direct AACHS. Airflow coming into the pack is distributed into individual battery modules (see more details of type flow paths in 9.3 of this document). Within the module, the airflow permeates the battery cells to exchange heat and maintain the desired temperature range for the cells.

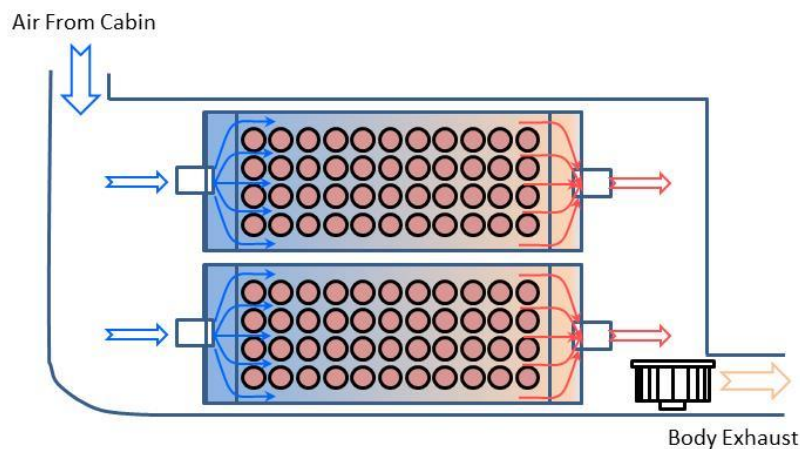


Figure 7 - Direct AACHS battery pack design

From the design point of view, the battery pack using direct air cooling/heating needs to be able to sustain the initial soaked high cabin temperature. This can be as high as 65 °C. The cabin temperature may take up to 25 minutes to cool down to the steady state cabin temperature in high thermal load conditions such as Phoenix, Arizona. For larger capacity batteries, this can be a challenge. To overcome this problem, the Dedicated Air Direct AACHS architecture of Figure 8 uses a dedicated HVAC assembly to provide low/high temperature air quickly, as soon as 1 to 2 minutes after the vehicle is propulsion capable. This way the initial transient cooling/heating of the battery after “propulsion capable” is ensured. A system is considered Dedicated Air if the airflow is directly conditioned by dedicated devices such as electric heating elements, an air conditioning system, or a heat pump system. The systems of Figures 8 and 9 below are considered Dedicated Air Direct AACHS architectures.

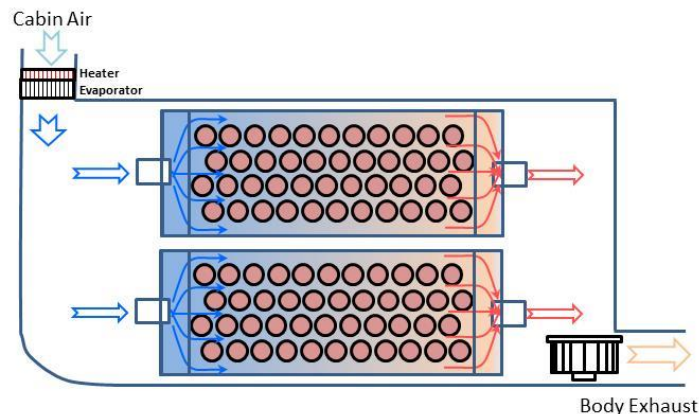


Figure 8 - Dedicated air direct AACHS

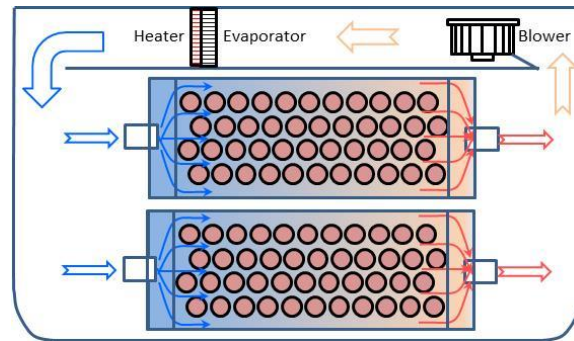


Figure 9 - Self-contained dedicated air direct AACHS

The architecture of Figure 8 still relies on the flow of the cabin air. It requires coordination of the automatic climate control system and the battery thermal management system to ensure proper amount of airflow through the battery pack. Careful calibration and controls algorithms are required to realize the coordination. To completely disengage the automatic climate control system from the battery thermal management, the variant system architecture of Figure 9 may be used. The self-contained battery thermal management system has a refrigeration evaporator and heater packaged into the battery pack. An internal air circulation fan moves the air through the evaporator and heater assembly to be conditioned, and then through the battery modules.

5.3 Application Notes

AACHS are applicable to battery systems with typical cell heat rejections less than 10 W/cell.

6. LIQUID COOLING AND HEATING SYSTEMS

Of the commonly seen methods of battery cooling/heating, liquid based thermal management systems, especially coolant based systems, are very effective and cost competitive. Liquid Cooling and Heating Systems (LCHS) aim to remove heat from or add heat to the battery cells in order to maintain the optimal working conditions for the battery cells. Most often, a single-phase fluid such as 50-50 ethylene glycol and water mixture is used as the heat transfer medium. Conditioned coolant at the required temperature is pumped through a battery pack to achieve and maintain optimal operating temperature. Battery thermal management systems may be classified according to the way coolant interacts with the battery pack. It is a Direct LCHS if the coolant is circulated inside the battery pack and between battery cells, and an Indirect LCHS if the coolant is circulated through cold plates or other extended surfaces. Additional differentiation may be made according to whether the coolant is cooled by a low temperature radiator or by a chiller as part of a refrigeration loop. For battery heating, the coolant is typically conditioned with a heater, but may also be warmed by a low temperature radiator.

6.1 Direct LCHS

Figure 10 shows a Direct LCHS composed of a coolant pump, a vehicle front-end low temperature radiator module, and the battery pack itself. Lines and hoses are used to make up the balance of the coolant circuit. As seen, the Direct LCHS battery pack allows coolant to flow through channels within the pack itself to absorb the heat generated by battery cells. Intricate coolant flow patterns are used to provide enhanced heat transfer. During cooling, higher temperature coolant exits the battery pack to enter the front-end low temperature radiator to dispose of the heat content. As is commonly practiced, the low temperature radiator imparts the coolant heat to an airstream generated by an electrical fan within the radiator module. The lower temperature coolant exiting the radiator is subsequently pumped by a coolant pump back to the battery back. Conversely, during heating, lower temperature coolant exits the battery pack to enter the front-end low temperature radiator to collect heat. In general, higher heat transfer performance, therefore better battery temperature management may be achieved with a Direct LCHS. The shortcoming of a Direct LCHS is mainly the complexity and the increased risk of an internal coolant leak.