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An Evaluation of Different Thermal Control Techniques for Valve Regulated Lead Acid (VRLA) Battery

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ABSTRACT: The VRLA battery is one of the most temperature sensitive battery. Slightly change in operating temperature is largely affect the performance and lifespan of VRLA battery. So, thermal control of VRLA batteries are most important for improving the battery life and performance. There are mainly two objectives of the thermal control strategy (1) to control the exchange of heat between each adjacent battery in battery pack and(2) to isolate the battery pack from environment. Always develop a thermal control strategy in such a way that the environmental condition inside battery packs remains within the optimum operational temperature range. There are mainly three types of thermal control techniques (a) A passive thermal control system which maintains the battery pack temperature within the optimum operating temperature range through thermo physical and geometrical considerations only. (b) A semi passive thermal control system involves the transfer of heat from hot to cold sink. (c) A active thermal control system involves the transfer of heat from cold to hot sink. In this paper, all of above thermal control techniques described in detail and evaluated the best thermal control method for VRLA batteries. Also summaries the different types of advance thermal control systems for VRLA battery.
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KEYWORDS: VRLA Battery, Phase Change Material (PCM), Thermal energy storage system, heat transfer, optimum temperature range.

I. INTRODUCTION

Proper thermal control of the battery pack is most important for improve the performance and lifespan of the VRLA battery. Proper controlling of the temperature inside the battery pack is reducing the risk of thermal runaway. So due to that reason thermal control strategy of battery pack should be equipped with for essential functions to ensure the right operating condition.

1. **Cooling:** During charging and discharging process heat is continue generated from the batteries. So temperature inside the battery pack is gradually increasing which responsible for reducing the life of the battery. Thus cooling function must be required in thermal control system for maintain the temperature around the batteries inside battery pack.
2. **Heating:** In cold climate, battery pack temperature fall down below the lower limit operating temperature range. This increases the internal resistance inside the battery. So heating function should be required.
3. **Insulation:** In extreme cold or hot climate, temperature of the battery pack is continuously varying. So, battery temperature rise and fall continuously out of the optimum operating temperature range. So prevent the batteries from variable climatic condition, proper insulation should be required.
4. **Ventilation:** Ventilation should be required to remove the hazardous gasses which generates during the charging – discharging process within battery pack.

The thermal control system for battery should be equipped with those components which able to fulfil the following functions. Here, outline the thermal control techniques which able to fulfil the required functions.

(a) Passive thermal control system
   (a) Thermal coating
   (b) Thermal insulation
   (c) Heat sinks
   (d) Phase Change Material (PCM)

(b) Semi passive thermal control system
   (a) Heater – Pump – Radiator fluid system
   (b) Heat pipes

(c) Active thermal control system
   (a) Vapor compression heat pumps
   (b) Vapor absorption heat pumps

II.PASSIVE THERMAL CONTROL SYSTEM

The thermal control system which able to maintain the battery pack temperature within the optimum operating temperature range through thermo physical and geometrical considerations only is known as passive thermal control system. There are mainly four different types of passive thermal control techniques.

A. Thermal coatings

Thermal coating is one of the highly thermal resistive material. Thermal coatings are placed over the outer surface of the battery to isolate from the solar radiation and uneven climatic conditions. Since there is no any moving parts and no any input power supplied required for thermal coatings. So it is one of the reliable options for thermal control system for battery. But one of the major problem associated with the thermal coating is degradation of the coating with uneven climatic condition around the year.

B. Thermal insulations

Thermal insulations are material which placed between two batteries in battery pack and whole battery pack is also insulated with the insulating material for isolates from climatic condition. The ability of the thermal insulating depends on the thermal resistivity of the material. The material with higher thermal resistivity is good insulating material. The most efficient thermal insulator is vacuum based multilayer insulation (MLI) composites. MLI composites made of alternative layers of reflective shields (generally used aluminum Mylar plastic) and low thermal conductivity material. Here aluminum based reflective shield reflects the solar radiations. The main two objectives of the thermal insulations are(1) to reduce the heat transfer between the adjacent batteries inside battery pack and(2) to isolate the batteries from uneven climatic condition.

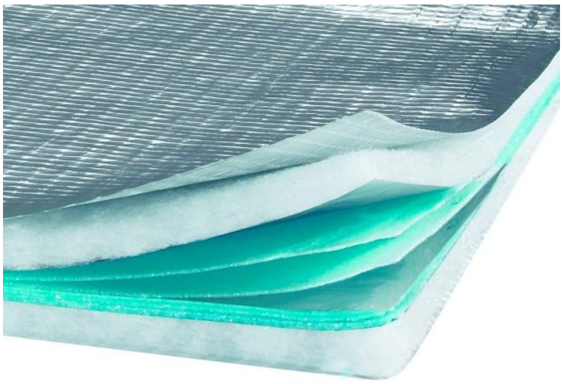

Fig. 2.1: Aluminized Multilayer Thermal Insulation

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C. Heat sinks:

Heat sink has a large heat absorbing capacity which is placed in thermal contact with surface of the battery. The heat generated from the battery is directly conducted in to heat sink. There large thermal capacity (mCp) of the heat sink allow only low temperature rise. The heat sink disposes the heat in atmosphere via convection heat transfer through some open part of heat sink. Heat sink is useful for those components which have a short operation periods so it is not more useful for long usage batteries.

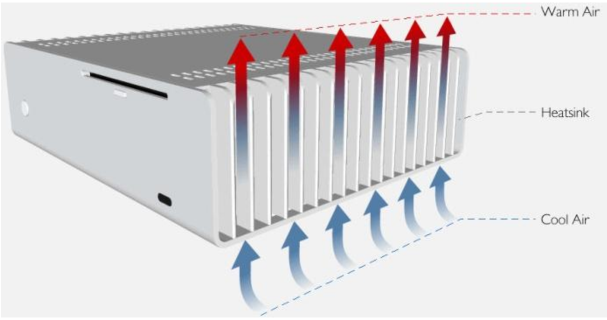

Fig. 2.2: Battery pack with heat sink

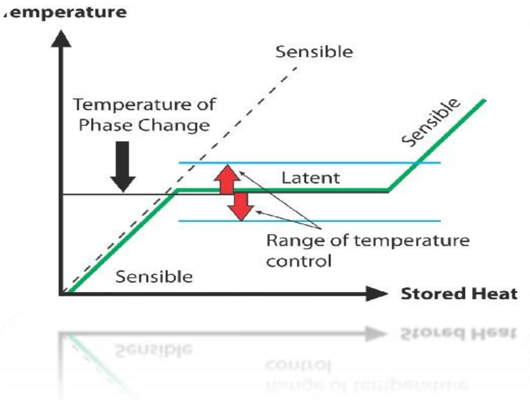

Fig. 2.3: The working mechanism of PCM on battery cells [6]

D. Phase Change Material (PCM)

PCM has a unique ability to absorb the librated heat from the body without appreciable change in temperature. Normally, PCM based thermal management system is one type of latent heat storage system. PCM is a type of material which absorbs the latent heat during the melting and stored up to the maximum and its release the heat during the changing from liquid to solid phase.[1] PCM able to store 5 – 14 times more heat per volume than sensible heat storage as water, clay etc. A large numbers of PCMs are available as per the required melting temperature range. There are mainly two types of PCM i.e. organic and inorganic. Normally, organic type paraffin wax popular in PCM based thermal control system.[2] PCM is absorbing the heat from the battery pack during operating condition and gradually melt. In cold climate, PCM around the battery pack in solid phase so its works as one type of insulator.

III. SEMI PASSIVE THERMAL CONTROL SYSTEM

A semi passive thermal control system is able to transfer the heat from hot to cold sink. It is not depends on the thermo physical properties of the material but its depends on the temperature of source and sink. In this system removal of heat from the battery during charging discharging process and transfer to the cold sink. There are two types of semi-passive thermal control system discussed below.

A. Heater – Pump – Radiator (HPR) fluid system

HPR fluid is one type of dynamic thermal control technique which continuously adds or removes the heat from battery pack for maintain the optimum operating temperature range. The temperature sensor detect the temperature variation of battery pack and send the signals to heater and pump for controlling the temperature and mass flow rate of the fluid. In HPR system radiator type heat exchanger is providing for cooling purpose and heater is providing for heating purpose. If batteries pack need cooling than coolant fluid from radiator provides cooling. If batteries pack need heating than additional heating provide by heater.

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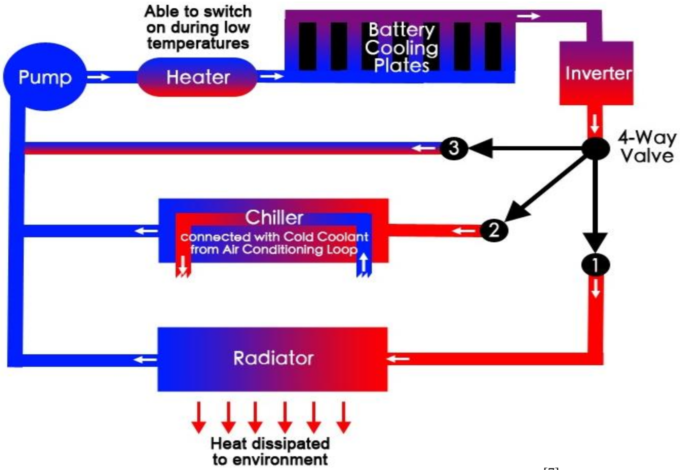

Fig.3.1 : Heater – Pump – Radiator (HPR) fluid system [7]

B.Heat pipes

Heat pipe is a two phase heat transfer system involves liquid – vapour phase change of working fluid. It is a closed evaporator – condenser consisting of a sealed, hollow tube whose inside walls are lined with a capillary structure. It made of three different parts: an evaporator, an adiabatic section and a condenser (shown in fig. 3.2). Inside the heat pipe working fluid in both phases i.e. liquid and vapour. Normally, water is used as a working fluid. Heat pipe has extremely high thermal conductivity. Evaporator side of the heat pipe physically contacted with the battery pack (shown in fig. 3.3). In evaporator portion, heat is absorbed by working fluid and it's converting to vapour phase. Due pressure difference, less dense vapour transfer to condenser side through adiabatic section. Condenser portion of heat pipe is physically contact with the heat sink. In condenser heat is rejected from vapour. Vapour is condensed in condenser and again back to liquid phase.

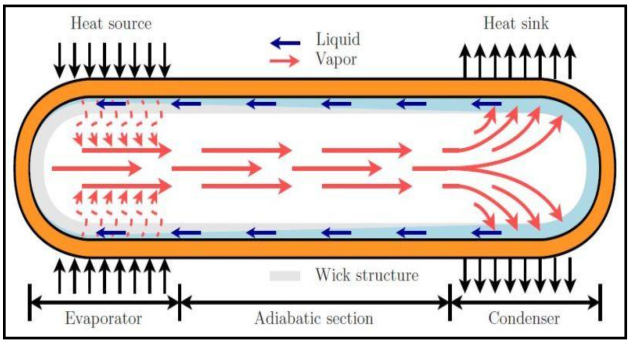

FIG.3.2: HEAT PIPE [8]

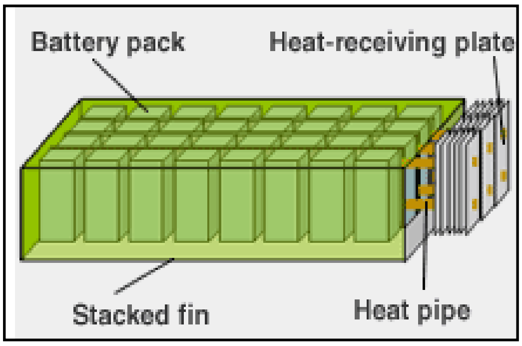

FIG.3.3: HEAT PIPE COOLING SYSTEM FOR BATTERY

IV.ACTIVE THERMAL CONTROL SYSTEM

Active thermal control techniques are opposite to other techniques. Because in an active thermal control system involves the transfer of heat from cold to hot sink. In which battery pack consider as a cold source and heat is transfer from cold source to hot sink through some external power input. Active thermal control systems are made of the some moving components, moving working fluid and some external power source. Different types of active thermal control system are explained below. [5]

A.Vapor compression heat pumps

A vapour compression heat pump works on the standard thermodynamic refrigeration cycle which absorb the heat from lower temperature sink and reject the heat to high temperature. The vapour compression heat pump composed with the four different processes (1) heat remove from the battery pack by evaporation of fluid. (2) Compress the

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fluid at high pressure and temperature in compressor. (3) Condense the working fluid in condenser or radiator. (4) Finally, expand the fluid by throttle device or cooling turbine. [3] The performance of this kind of heat pump system can be measured by comparing with Carnot refrigerator working between same temperatures.

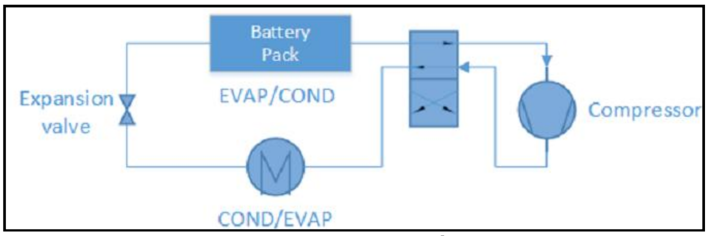

Fig. 4.1: Vapour compression heat pumps

B. Vapor absorption heat pumps

Normally, the vapour absorption heat pump is use for high capacity and large scale of battery pack. The working of vapour absorption heat pump is same as a vapour compression heat pump but only compressor is replaced with absorber – generator.

V.ADVANCE THERMAL CONTROL SYSTEM

The advance thermal control systems are categorized mainly in two different sections i.e. advance Heat spreading technologies, heat transfer technologies. All the advance thermal control systems explained below in brief.

A. Advance heat spreader technologies:

The performance of the heat spreader technologies depends on the effective thermal conductivities of materials. Higher thermal conductivity reducing the temperature gradient and improve cooling effectiveness. Presently heat spreader technologies based on solid material Cu, Al, Cu –W which has a higher thermal conductivity. Here we discuss two different spreader technologies i.e. oscillating flow heat spreaders and vapor chambers.

(a)Oscillating flow heat spreaders
Oscillating flow heat spreaders remove the heat from a battery pack and spread over a larger area by mechanically oscillating fluid in a channel. It is a famous because of some advantages like it does not need any type of reservoir. Less temperature gradient between source and sink.
(b)Vapor chambers
Vapor chamber is made of planer heat pipes. Mostly vapor chamber used of very small batteries. Planer heat pipes are particularly arranged with the pack of small batteries. The planer heat pine in a vapor chamber has a best ability to spreading the heat two dimensionally.

B. Advance heat Transport technologies:

The heat transport technologies work on principle of transfer of heat from high temperature source to low temperature sink. Best example of the heat transport technology is to pump liquid cooling loop for transport the heat from battery pack to radiator in hybrid automobiles. It works on concept of larger heat transfer coefficient reduces the temperature gradient between battery pack and working fluid.[4] One of the advance heat transport technology capillary two phase loop explain below in brief.

The concept of capillary two phase loop is same as a heat pipes. It is one type of the heat transfer device that uses the capillary force in the evaporator wick to circulate the two-phase flow (Liquid – Vapor). It is composed of following components (a) Capillary evaporator is responsible for generating the capillary force for working fluid. (b) Condenser (c) Reservoir (d) Liquid – vapor line. Shown in fig. 5.1

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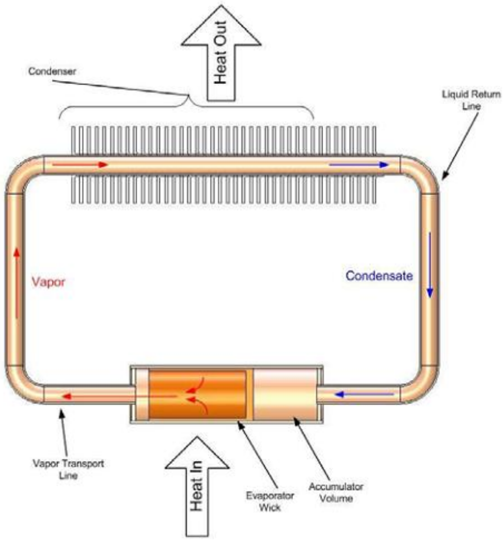

Fig.5.1 Capillary two phase loop heat Transport technology

VI.CONCLUSION

VRLA battery is most temperature sensitive battery. Performance and life span of the battery are affected by the temperature. Therefore proper thermal control of the VRLA battery is most important for improving the performance and life of the battery. Here by we have discussed the various types of thermal control techniques. Among all the types, in passive thermal control techniques give better temperature uniformity, active thermal control system is reducing the temperature gradient between battery pack temperature and working fluid. The performance of advance thermal control techniques is better compare to conventional techniques but those are normally applicable to thermal control of small batteries. One of the disadvantages of the active cooling system is more moving parts in a system. Finally, Through the trade-off of different thermal techniques mentioned above, we conclude that two cooling systems are recommended i.e. Phase Change Material (PCM) passive cooling system and heat pipe based cooling system. Here by, we recommended these both thermal control systems according to performance of the system, is described as a score and the importance of the component is described as a weighting factor. PCM cooling systems is performing better on thermal management of VRLA battery compare to others.

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