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A Review on Recuperative Cooling of Li-Ion Batteries in Electric Vehicles

Prudhvy Raj Veeravarapu and Rohit Kulkarni(under graduates in mechanical engineering)
in guidance of asst. Professor Agir Kalyan; Mechanical engineering department, Matrusri engineering college, Hyderabad, India

Abstract:- A Recuperative cooling mechanism was designed to improve the battery life of an electric vehicle which suffers from premature aging or degradation due to the heat generation during discharging and charging periods and also improving the performance of the vehicle. The cooling effect is produced by the bleeding of the refrigerant from the refrigeration system, thereby increasing the cooling effectiveness and reducing the cost by eliminating the conventional cooling equipment. Several initial and final boundary conditions were set based on the past studies. The analysis revealed that the temperature across the surface of the battery is in the range of 20 - 25°C, which is in the safe operating temperature of the battery.

I. INTRODUCTION

Upon depletion of the crude oil resources, the demand has been increased for alternative sources. To reduce the pollution and improvise the green technology, the invention of electric cars paved a way for commuting purposes. Automakers have gone into developing the electric vehicle technology. Vehicles which do not pollute the environment show a very promising sign for the future development in automotive industries. However, electric vehicle is still in juvenile stage where several models that were manufactured mainly for experimental purposes and market research. Automakers continue to improve their respective models to be made into the mass market for consumers.

Till date electric vehicles (EV) incorporated cooling systems for their batteries, either a liquid cooling system or an air cooling system. Usually electric vehicles are deployed with Li-ion batteries which are very efficient and effective. These batteries provide very low weight to power ratio, high fuel economy, wide range of speeds and less noise. When compared to other batteries, Li-ion batteries provide good life in the course of its run.

A. Li-ion batteries have the following advantages:

➢ *Optimum Electrical Energy*

The lithium-ion batteries have high optimum electrical density.Small applications such as mobile phones require very less amount of energy but, in the case of electric cars,the requirement to run the 3-Ø A.C. motors is high.Lithium ion batteries facilitates that requirement.

➢ *Self Discharge*

The only disadvantage we come across with rechargeable batteries is its self discharge.Its is very low compared to Ni-cadmium and Ni-MNH forms.

➢ *Minute Maintenance Costs*

Some of the batteries like Ni- cadmium and Ni MNH require maintenance for optimal performance.The maintenance parameter is not considered in Li- ion batteries.

➢ *Free of Priming*

Batteries such as Ni-cadmium and Ni-MNH require priming during ttheir first charge.The lithium ion batteries do not require priming.

➢ *Multi Purpose Batteries*

Depending upon different loads required for different applications,Li-ion batteries can be utilized in various ways.

B. The Disadvantages Include,

➢ *Necessity to be Protected*

The lithium –ion batteries may be damaged when there are voltage fluctuations during charging or current fluctuations,this should be avoided. The safe operating temperatures of the battery is in between 12◦C-45◦C.If it exceeds or preceeds the specified value, the chemical reaction in the battery gets hindered and inturn performanve gets reduced.

➢ *Premature Ageing*

The specified charging and discharge cycles for Li-ion batteries is around 500-1000 cycles.But before attaining the range, it fails. So, the ageing of the batteries should be avoided.

➢ *Transportation Limitations*

Li-ion batteries are transported through aeroplanes with a limitation, the vital way for transporting these batteries is through ships.This increases the necessity for establishing the production units upon the usage requirements.

➢ *Expensiveness*

The cost is another parameter considered for the usage of Li-ion batteries.They are costlier than Ni-cad, Ni-MNH cells.

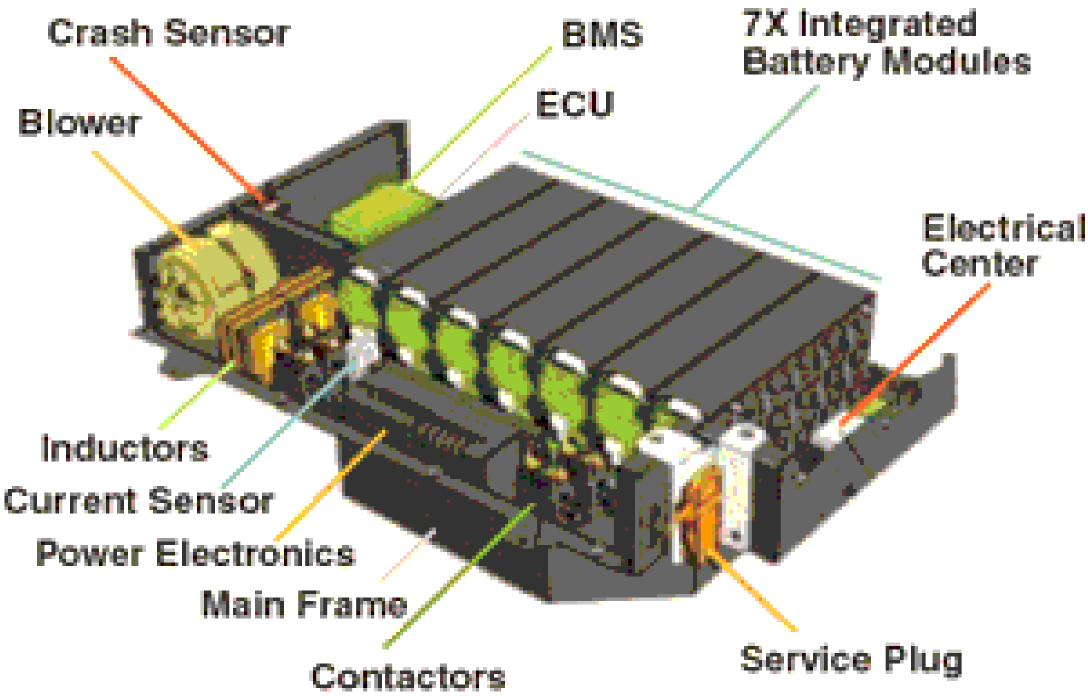

Fig 1

II. NECESSITY OF COOLING

To improve the life of the Li-ion battery, effective cooling system is to be provided which overcomes the vital disadvantages. In general, liquid recirculating cooling systems or air cooling systems are employed. The problem with liquid cooling system is incorporation of pumps and pipes, increases the weight of the vehicle.

The problem associated with air cooling system is it is not effective as liquid cooling system. Hence, we developed a cooling mechanism which facilitates effective cooling and also increases the coefficient of performance (COP) of the air conditioning system of the vehicle.

III. LITERATURE REVIEW

- ➢ *Analysis and Experimentation for Effective Cooling of Li-ion Batteries*

They mentioned that the cooling of the battery of an electric vehicle can be done by free convection and forced convection of the air.They found out the convection heat transfer coefficient(hc) of air by
h=Nur/d, where Nu =Nusselt's number r=thermal conductivity of the liquid d =characteristic length

By altering the values of reynolds number for forced circulation, the heat transfer coefficient is then found and the coolant(air) is circulated.

The temperature difference attained in the battery during charging is given by

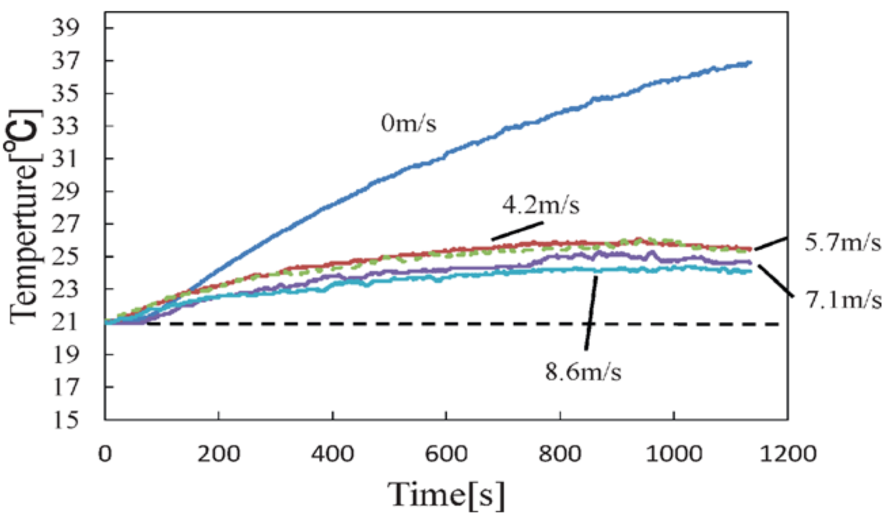

Fig 2

The state of charge(SOC) during charging at different heat resistances is given during charging of an electric battery which affects the performance and reliability is given by,

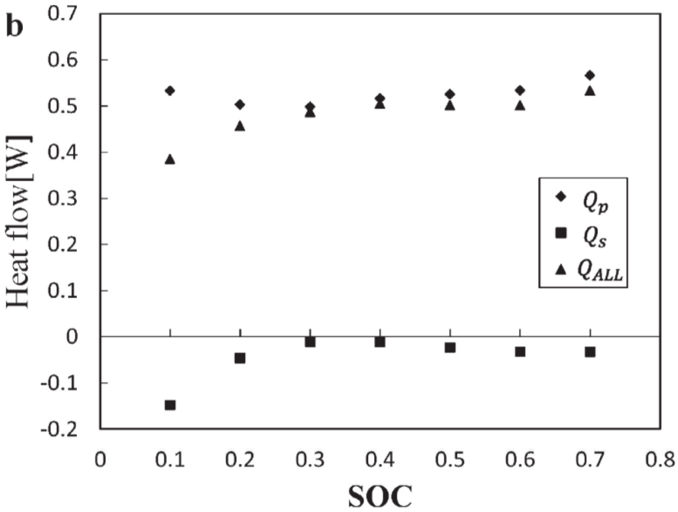

Fig 3

The only problem associated with this is utilization of additional power for running the fan during charging as well as when the battery is heated.

IV. CONTROLLED COOLING IN HYBRID ELECTRIC VEHICLES

They proposed a cooling system similar to the radiator for a hybrid vehicle i.e., usage of both IC engines and Electric engines

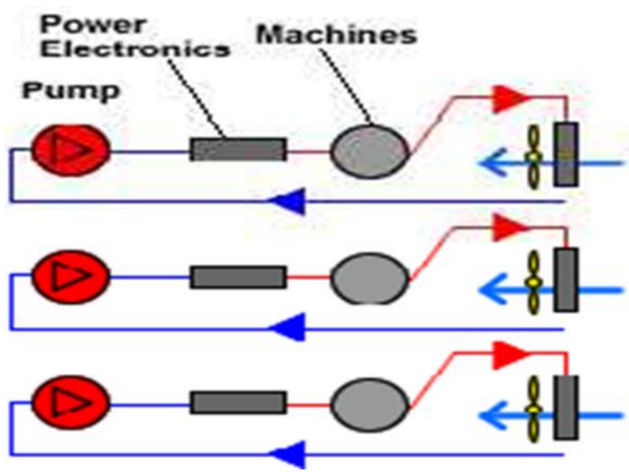

Fig 4

The temperature drop attained in each stage of the given 3 stages is only 3.7◦C which accounts to a complete drop of 3.7 *3=11.1◦C .So the cooling system cannot attain required temperature drop which alters the state of charge (SOC) and performance of the electric vehicle.The cooling of the vehicle is accomplished by passing the coolant surrounding the engine components and is force cooled by the help of a blower fan, creating a temperature difference.

V. FAN-PAD EVAPORATIVE BATTERY COOLING FOR HYBRID ELECTRIC VEHICLE THERMAL MANAGEMENT

They suggested a pad equipped with a fan for battery cooling system. The battery management systems(BMS) generally aims to maintain temperature at a range of 20◦C-45◦C by maintaining the battery state of charge (SOC) at the required levels.

The lithium-ion batteries which are used now have a portable advantage .But the main disadvantage is its ability to reach the optimum temperature during operation, minimizing the performance. To reduce the constraints mentioned above and maintaining the SOC of 70% and not below 40% for faster recharge and regenerative breaking capability. The temperature limits are considered to be around 20◦C-45◦C .The temperature should not be less than 20◦C which hinders the chemical reaction and should not be beyond 55◦C which constraints the performance of the batteries. The cooling systems generally used are air and liquid cooling systems for effective cooling .Liquid cooling is accomplished by circulating coolant in separate tubes which maintain contact with the battery. The flow may be a counter flow or a parallel flow and the flow is facilitated by the pump provided The air cooling systems generally uses a blower and fin type assembly which transfers heat to the surrounding atmosphere by convection heat transfer(air as a medium).

They innovated the cooling system by creating a perforated membrane which allows forced circulation of air in one direction and water droplets(moisture) topass through the membrane in another direction. Two cellulose membranes(perforated pads) are 12.7cm thick are located along the width and length of the battery.

The directional flow of water and air enables the battery to cool in more effective way compared to liquid and air cooling. The mathematical governing equation is given as

$M_a dh_a = [h_c (T_w - T_a) + K (W_{asw} – W_a) h_{vs}] da$

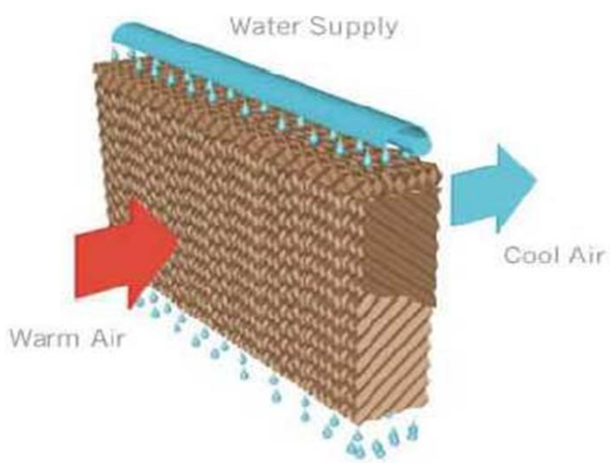

Fig 5

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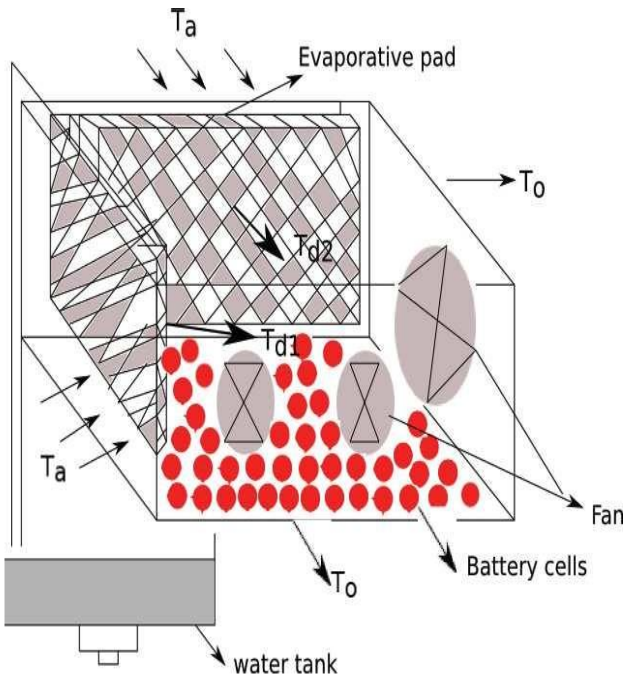

Fig 6

VI. METHODOLOGY

The refrigerant used here is Dichloro methane (CH_2Cl_2). The mechanism of the refrigeration cycle is shown below.The recuperative mechanism,

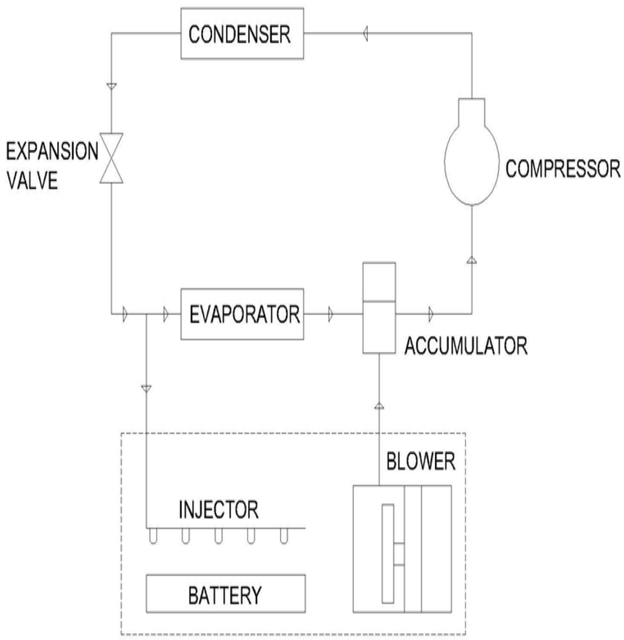

Fig 7

In the above mechanism, a thin copper sheet of less than 2 mm is soldered to the battery pack. The used refrigerant is made to bleed after the expansion valve into channelised pipes where it is atomized to fine particles by an injector (nozzle).

The boiling point of Dichloro methane is 39.65°C and the temperature at which it is bleeded is about 0°C. The injector sprays the refrigerant onto the heated surface of copper sheet, where it absorbs heat and vaporizes. An artificial draught is created which enables the vapour to pass into the accumulator. As the refrigerant is vaporized absorbing heat from the space of battery pack, the surroundings along with the battery pack gets cooled down to a temperature range of 15 - 20°C.

As the refrigerant is bleeded from the refrigerating system, the load on the evaporator gets reduced, which in turn improves the COP of the system.

The convective heat transfer coefficient can be given by (h^c)= Q/A*(T2-T1)(hc= 22W/m2k)
Where,Q = Amount of heat to be rejected from the air space of battery pack so that cooling occurs
A= Surface area of the battery pack (1 m2)
T2=Temperature of the air near to the battery (42°C)
Q=hcA(T2-T1)________________________________ ①

T1=Temperature to be attained in the space provided (15°C, 18°C, 20°C)

The amount of heat to be rejected can be given by the equation (i.e., refrigeration) =m C^P(T1-T3)__________ ②

Where,m= mass flow rate of the refrigerant through the injectors(nozzles) provided
CP=specific heat of the refrigerant (dichloro methane)(1210J/Kg K)

T3=Temperature of the liquid refrigerant after expansion valve (assuming it to be 0°C)
T1=Temperature of the cooled space

Now, equating 1 &2 we get, m=hcA (T2-T1)/C^P(T1-T3) in Kg/sec

For cooling the space to a temperature of space to 15°C, we require 594J of energy (air temp. taken as 42°C) so
m=22*1*(42-15)/1210*(15-0)=0.0327Kg/sec______15°C
m=22*1*(42-18)/1210*(18-0)=0.0240Kg/sec______18°C
m=22*1*(42-20)/1210*(20-0)=0.0200Kg/sec______20°C

VII. CONCLUSION

The methodology so far discussed in this research paper is based on the fact that the refrigerated space always maintains a steady temperature, there by reducing the temperature of the battery.The assumptions which are made and reviewed are based without any experimental analysis.The experimental results may differ.However,the toxic nature ,leakage capability and inflammability of the used refrigerant are not discussed in this review paper which might vary the cooling characteristics.

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