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Review Paper on Battery Thermal Management System of Electric Vehicles

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Abstract - **Nowadays Electric vehicles (EV) develop fast in current market and have become popular due to its zero emission and high efficiency .However there are many factors to limit its performance, cost, lifetime and safety of battery. So, the management of batteries is necessary to increase its performance when operating at various conditions. The battery thermal management system (BTMS) is introduced to control the thermal behaviour of batteries. In this paper we will see about BTMS technologies such as air cooling system, liquid cooling system, direct refrigerant cooling system, phase change material (PCM) cooling system. These systems are analysed through their performance, weight, size, and cost.**

Keywords —EV, Battery thermal management system, BTMS, Air Cooling system, Liquid cooling system, Direct refrigerant system, PCM.

I. INTRODUCTION

There are different blending levels of electric cars are available, according to their blending level, various size, type, and number of battery cells are mounted in EVs [1]. Nowadays,, lithium ion cells are used in most of the EVs. These Battery cells generate large amount of heat during charging and discharging, this happen because of internal resistance in battery cells. This heat generation causes temperature rise in battery pack. The thermal behaviour of batteries influences their electric and chemical reactions. So always ensure about proper working of battery pack, that they must be operates properly with in certain temperature range i.e., the battery must be performs efficiently and has longer life.

That's why a Battery Thermal Management system (BTMS) will normally integrated with battery cells. This requires vital knowledge about the proper working requirements of batteries, and which system is more reliable and efficient.

II. TECHNOLOGIES OF BTMS

A. Air Cooling

Air Cooling system uses air as the thermal medium. Air used in the system can be either from atmosphere or from the evaporator of cooling system [1]. This system divided into two systems passive cooling system which uses air from the atmosphere or blower and active cooling system which uses evaporator of air conditioning [1]. In passive cooling system forced air used to cool batteries is not so much effective because in ambient temperature range 45°C-50°C the temperature inside the battery pack exceeds 55°C which is beyond the operating temperature and causes thermal runaway [1]. But the uniformity of temperature distribution also affected by flow rate of air, this causes temperature difference can be even more 5K [1].In, active cooling system evaporator is uses to cool air, which is supplied to battery pack for cooling. This system is more reliable than passive cooling system due to separate evaporative cooling system. This active cooling system work with computer controlled BTMS for maintaining internal temperature of the battery using air conditioning unit [5].

B. Phase Change Material (PCM)

Phase change materials combine latent heat and sensible heat absorption capabilities which makes them promising candidate in wide range of heat transfer applications such as battery thermal management system [1]. PCM has high fusion heat which stores and releases amount of heat during melting and solidifying at a point. But, PCM has low thermal conductivity that's why fins are used to increase heat transfer rate. Also, melting of PCM is affected by buoyancy forces that's why alignment of fins have an essential role in performance of btms [3]. Air cooling and water cooling are two conventional methods used in thermal management of batteries but these methods are power consuming methods that's why lowering the energy consumption has encouraged researchers to move towards inventing PCM system. This system uses melting enthalpy changes to absorb heat from the hot battery and cool it down while changing from solid to liquid. Due to low thermal conductivity of PCM material internal fins between PCM are used to enhance heat transfer rate. This effect is studied by using nanofluid phase change material by adding small amount of multi walled carbon nanotube (MWCNT) in liquid paraffin to increase heat transfer specifications [3]. In order to use PCM as a heat transfer fluid it is poured into

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spherical capsules, flat panels or circular tube and located beside battery. Heat transfer researchers are interested in using various techniques to study melting of PCM in vertical tubes. One of the technique is using melting of paraffin wax in thin walled tube made up of carbon tube [3]. Another is using melting of pure materials and mixtures, assuming pure substances have a well defined and constant melting point while mixture melts at specific range of melting point [3]. But this causes difference in solid shapes of pure and impure materials.

So as stated above the main drawback of using paraffin wax is low thermal conductivity and low rate of solidification and melting/boiling point. In this case scientist uses different methods to find out which material best for the PCM system. And after investigation graphite as a additive is found out which has high tensile strength and burst strength as compared to paraffin wax [3]. Also carbon fiber is another suitable additive in PCM composites. Carbon fibers are composite with paraffin wax to enhance heat transfer rate [3].

It is important to note that cost is one of the major factor for deciding the material. In this regard, employing aluminium small and light-weighted fins can be superior to expensive additive like carbon fibers [3]. The alignment of fins is one of the major factor in PCM system as melted liquid part which has generally lower density occupies upper part and non melted part of higher density occupies lower portion of container. So fin alignment plays dominant role in gravity and buoyancy of material. Therefore fin alignment relative to the gravity field direction plays an important role. So different cases are studied which uses different angle of aluminium fins relative to gravity field which contains paraffin wax as PCM [3].

C. Liquid cooling system

Liquid is another heat transfer fluid to transfer heat. There are generally two groups of liquids used in thermal management system. One is dielectric liquid (direct-contact liquid) which can direct contact with battery cells [1]. Another is conducting liquid (indirect-contact liquid) which can only indirectly connected to battery cells and generally it contains ethylene glycol and water [4]. Different liquids also used by using different layouts. In direct cooling the normal layout is to submerged module into mineral oil [1]. For indirect cooling system battery cells are surrounded by water jackets which contain water glycol and water as a heat conducting medium [4].

In indirect cooling system jackets which are used as heat conduction passage may be made of relatively high heat conductivity such as metal. These jackets which are used as heat conducting medium are arranged in axial direction with battery cells 1011 [2] as shown in fig1. Then, heat conducting medium is divided into two passages or channels 201 and 202,in which one insulation layer 203 is present between these two passages 201 and 202 to restrict the contact between two channels as they are high heat conducting mediums [2]. And this insulation layer 203 is generally made up of insulating material which have high heat insulation such as glass fiber, asbestos, rock wool [2].

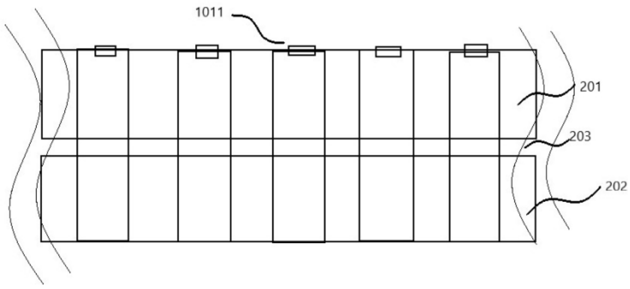

Fig. 1 (2, US patent, 2018)

These two passages or channels 201 and 202 work as a counter flow heat exchangers, to increase the heat transfer rate. Again these passages divided into two sub-channels for better cooling as shown in fig 2. The 201 channel is divided into 2011 and 2012. And 202 channel is divided into 2021 and 2022. Channel 2011 has one inlet 2011i and one outlet 2011o and similar arrangement for 2012, 2021 and 2022.Both 201 and 202 channel are arranged in such way that glycol flow in these medium have opposite directions to increase heat transfer rate of battery pack [2].

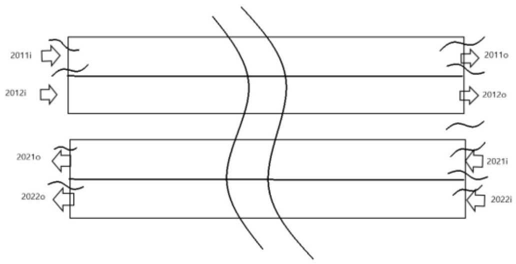

Fig 2 (2, US patent, 2018)

Later on these conducting channels is connected by port connecting devices in heat conduction passage. From fig 3, given below here are two port connecting devices 301 and 302 which are connected to inlet/outlet of heat conduction medium passage. Again these port connecting devices are divided into two parts. The 301 device is divide into 3011 which is inlet of 201 passage and 3012 which is outlet of 202 passages. similar arrangement for 302 port by dividing this port into 3021 and 3022 [2]. In this way these port connecting devices communicate with heat conducting medium.

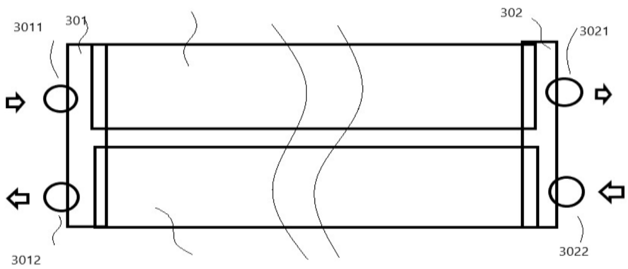

Fig 3 (2, US patent, 2018)

This Liquid cooling system also categorized into active and passive cooling system according to different sinks for cooling [1]. In passive liquid system, heat sink for cooling is radiator. This system is no ability to heat. Heat transfer fluid is circulated by pump situated in the closed passive system, which absorbs heat from the battery. But this system is ineffective when there is small temperature difference between battery pack and ambient air temperature. That's why active liquid cooling system is used for better heat transfer rate. In this there are two loops first loop is same as passive cooling system and other is actual air conditioning loop, and in this system instead of radiator evaporator is uses for proper working of active cooling system. Also the function of direct refrigerant cooling system is same as a active liquid cooling system, only difference is it uses refrigerant directly as a transfer fluid [1].

III. Math

To predict the efficiency of liquid cooling system, heat transfer is generally expressed by overall heat transfer coefficient, which is given by following equation [1]

$$q = U * A * \Delta Tm$$

where

q =Heat transfer rate [W]

U =Overall heat transfer coefficient [W/ (m²·K)]

A=Heat transfer surface area [m²]

ΔTm= Approximate mean temperature different [K]

This equation includes the conductive and convective heat transfer of hot and cooled liquid.

For calculation of indirect cooling system which we discussed above, have unfinned , tubular structure heat exchangers, equations will be[1]

$$\frac{1}{UA} = \frac{1}{hi*Ai} + \frac{R"f,i}{Ai} + Rw + \frac{R"f,o}{Ao} + \frac{1}{ho*Ao}$$

Where,

R"f,I and R"f,o are fouling factors.

hi, ho are convective heat transfer.

Ai, Ao Contact area of inner, outer tube of surface

Equation for heat balancing within heat exchangers [1],

$$\frac{dEst}{dt} = \dot{E}n - \dot{E}o + \dot{E}g$$

Est =stored mechanical and thermal energy

$\dot{E}g$=Thermal Heat Generation

$\dot{E}o$, $\dot{E}n$ = Thermal and mechanical energy transport at inlet and outlet of control surface.

IV. Discussion

In this paper we saw the three cooling systems which are used in electric vehicles to cool battery. The air cooling system which we saw is not so much efficient due to its less heat transfer capacity. Then we saw PCM system, which is efficient but it is not used yet in any EVs. Finally, we saw liquid cooling system which is more reliable than air cooling system. Nowadays, this system is used by many manufactures like tesla for efficiency of their electric car battery.

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