Designing of a coolant based battery cooling system in an electric vehicle

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ABSTRACT

The project is to design a coolant based battery cooling system in an electric vehicle. In the recent years, electric vehicles have developed quickly and have become popular due to their zero emissions and high tank to wheels efficiency. However, some factors limit the development of the electric vehicles, especially performance, cost, lifetime and safety of battery. Therefore the management of batteries is necessary in order to reach the maximum performance when operating at various conditions. The battery thermal management system plays a vital role in the control of the battery thermal behavior. The battery thermal management system technologies are air cooling system, liquid cooling system, direct refrigerant cooling system and phase change material cooling system. Battery thermal management system is critical to dissipate the heat generated by the battery pack and guarantee the safety of the electric vehicles. In this paper, study is made on different cooling system and heat pipe is designed to remove the heat generated by electrical battery. Heat pipe is modelled using CAD software. The cooling of the battery is very important because it improves the efficiency of the battery and there are various process through which battery cooling system is done. In this research the cooling of the battery takes place with the assistance of the coolant which is passing through the heat pipe. Liquid cooling system is very helpful for cooling system of the battery and in this research it is the liquid cooling being employed and using different coolants for achieving efficient cooling rates .

Keywords:*-battery thermal management, Coolant, heat pipe*

1. INTRODUCTION

Living in the 21st century and in this present time, many kinds of climatic changes have already taken place for example global warming, change in temperature etc. and as far as studies and researches are concerned, almost half of this is done by the automobile emissions that are being used by people for various reasons on daily routine basis. The exhaust that comes out of those automobiles from silencers, they contain greenhouse gases and those gases trap the sun’s heat and don’t let that heat to escape and hence it results in the increase in earths temperature.

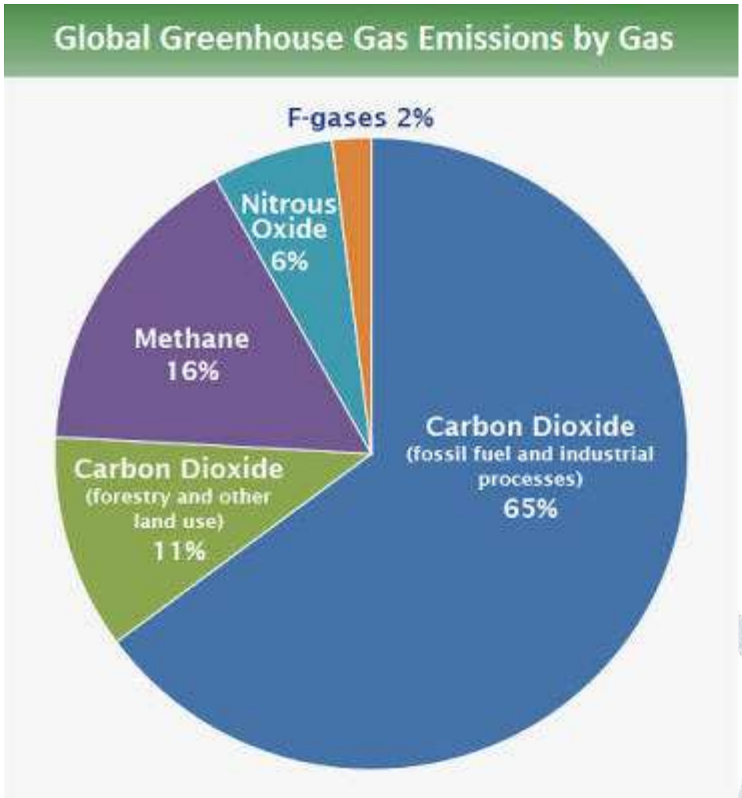

Figure 1. Global Greenhouse Emissions

The following stats are of the year 2018 and reflect the Co2 emissions data estimate from same source of different countries. This data only takes into consideration the carbon dioxide emissions from the burning of fossil fuels.

Table 1. Carbon dioxide emission percentage

Rank	Country	Co2 emissions
01	Saudi Arabia	18.48 T
02	Kazakhstan	17.60 T
03	Australia	16.92 T
04	United states	16.56 T
05	Canada	15.32 T
06	South Korea	12.89 T
07	Russian Federation	11.74 T
08	Japan	9.13 T
09	Germany	9.12 T
10	Poland	9.08 T
11	Islamic Republic of Iran	8.82 T
12	South Africa	8.12 T
13	China	7.05 T
14	United kingdom	5.62 T
15	Italy	5.56 T
16	Turkey	5.21 T
17	France	5.19 T

18	Mexico	3.77 T
19	Indonesia	2.30 T
20	Brazil	2.19 T
21	India	1.96 T

The numbers mentioned above in the table clearly point towards the fact that the emissions of harmful gases rise continuously by the burning of fossil fuels and that leads to the changes in climate such as increase in temperature, green house gas effect, depletion of ozone layer and many more adverse health effects in human beings.

Also at the same time, there is a scarcity of fossil fuels, it points directly towards the fact that these fossil fuels are present in a limited in nature which means that one day mankind will be running short of fossil fuels. All these things directly point towards the need of employing some alternate ways in the automobile industry. So this is a proper time to move or switch towards the electric vehicles as these electric vehicles produce zero emissions and are completely eco-friendly and due to this reason, electric vehicles have gained a lot of praise and market share in a very less time. Further adding more to it, there are many more reasons to switch the gears towards the electric vehicles from the conventional gasoline powered vehicles.

Comparison between electric vehicles and gasoline powered vehicles:-

While having a glance from the surface, both gasoline and electric vehicles could seem to be the identical but while analyzing it from the within, it is clearly visible that it's a complete different story. The components of an electric vehicle are unique and different as that of gasoline vehicles but do serve the identical function as they are doing just in case of gasoline vehicles.

Another major difference between electric and gasoline vehicles is that of number of moving parts. The electric vehicle has one moving part and which is motor, and in comparison to that, the gasoline vehicle has a many moving parts. The electric vehicles needs less maintenance and is more reliable. The upkeep costs similarly are less.

Table 02. Comparison between gasoline and electric vehicles

Gasoline vehicles	Functions	Electric vehicles
Gasoline tank	It is used to store the energy that in turn is used to run the vehicle	Battery
Gasoline pump	It replaces the energy to run the vehicle	Charger
Gasoline engine	It is used to provide the required force required to move the vehicle	Electric motor
Carburetor	It is used to control acceleration and speed	Controller
alternator	It is the main source to provide power to accessories	DC/DC converter

2. LITERATURE REVIEW

After consulting and reading different research papers that time directly towards this project and people papers are for the same reason being taken into consideration for the literature review. After probing them, it is clearly understood that it's the time and want of an hour to maneuver towards the electric vehicles but at the identical time there are kind of things that hamper the event of the electric vehicles, especially performance, cost, lifetime and safety of battery. Therefore, it is necessary to possess the correct battery management systems so as to realize the utmost performance while operating at various conditions. The battery thermal management system plays a really important role while controlling the thermal behavior of the battery. The battery thermal management system technologies include air cooling system, liquid cooling system, direct refrigerant cooling system and phase change material cooling system. Battery thermal management system is critical to dissipate the heat generated by the battery pack and guarantee the protection of the electric vehicles. The optimum operating temperature range for lithium ion battery is between 25-40 degree Celsius. During this paper, study is formed on different coolants that may be used so as to dissipate maximum heat and achieve maximum efficiency and also heat pipe is supposed to induce obviate the heat generated by electrical battery.

After inquiring a groundwork paper named Design and analysis of heat exchanger for battery thermal management system by Hanumant Yaragudri, Mohan Narayana K, Ravikumar M, (Ref. No. 01)The findings include, in order to stabilize the temperature of a battery pack of an electric or hybrid vehicle, it is necessary to own a well designed thermal management system, because it will help in optimizing the battery temperature and also the battery temperature will remain within the desired range of operation. Also, from this paper, it directly points towards an idea about the various configurations of a battery cooling system and their merits and de merits also. Hence, being clearly understood that for a Li-ion battery, it is the indirect liquid cooling that is the foremost suitable option to opt for.

Another paper named as Journal of energy storage 32(2020) (Ref. No. 02) after being studied, the findings were that while designing a cooling system for a battery or a cell, many more temperature gradients are present already that do affect the performance of a battery cooling system that is during this case a heat pipe. In practicality, cooling systems may keep the temperature of the battery under operating range but different temperature gradients are chargeable for affecting the cooling performance of thermal management system of an electric battery pack.

Similarly the findings from the paper named as International journal of heat and mass transfer (Ref. No. 03) were that it's the time and need of an hour to switch to electric vehicles as such vehicles employ batteries and that produce zero emissions and zero pollution. In order to have a suitable and maximum thermal performance of a battery pack, analysis for the optimization being performed, that too at two extreme operating conditions. By performing the analysis it points clearly towards the fact that there are a number of important factors that are chargeable for the thermal behavior of the battery. Among many other factors, the two most vital factors are inlet temperature and also the inlet flow.

"Optimizing the heat dissipation of an electric vehicle battery pack" (Ref. No. 04) named another research article, after being studied clearly directs towards the fact that this paper also agrees to the actual fact of need of employing electric vehicles over gasoline ones and also sensing the need and importance of getting an efficient battery thermal management system so as to keep the battery under optimum operating range. This paper being focused on employing the trendy type technique of air cooling ventilation system for a battery of an electric vehicle instead of going with the conventional one. The new kind of this technique includes new shape of outlet, replacing the cooling air inlet and outlet location. By employing such methods, better thermal management of a battery is possible.

For a lithium ion battery, in order to design an efficient thermal management system, then there is a need of possessing proper design strategies and do comprehensive thermal analysis is also being required. This study focuses on the planning of designing a heat pipe for battery thermal management system of a lithium ion battery. The material used for the heat pipe is copper having internal diameter as 3.5 mm.

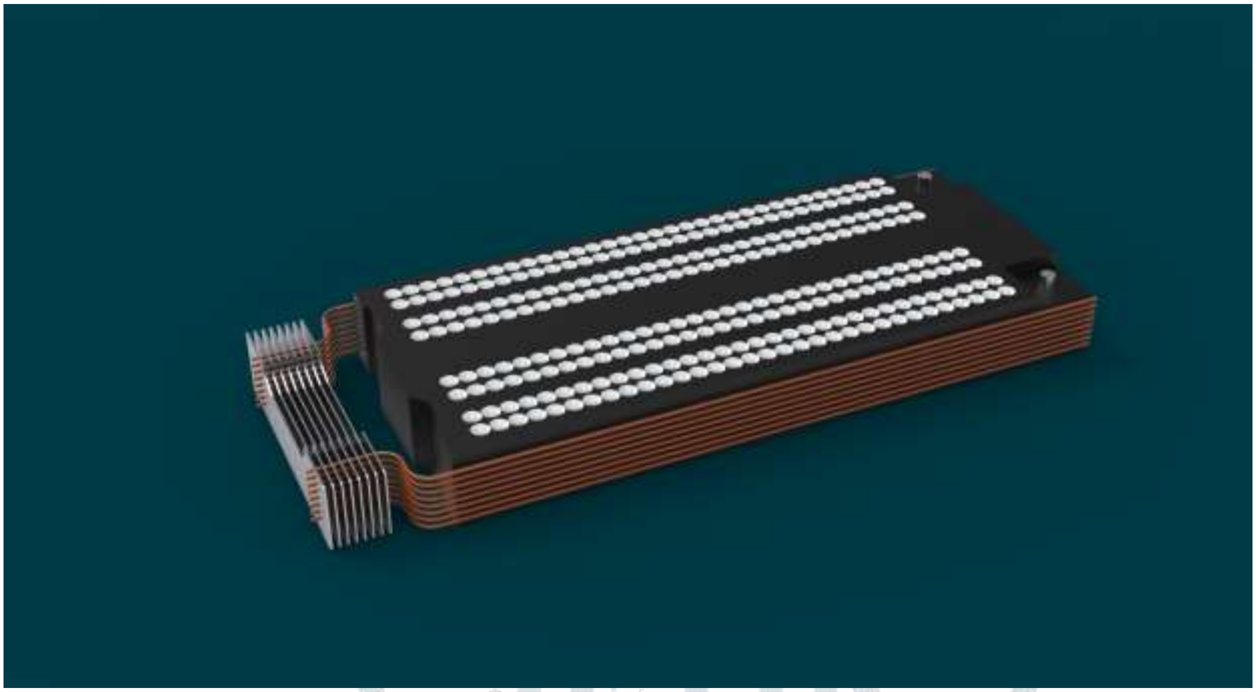

Figure 2. CAD model of a heat pipe

Table 03. Battery Specifications

Battery name	Height	Width	Length	Weight	Cell voltage	Total number of cells used
Electric vehicle	3.1 inches	11.9 inches	26.2 inches	55 pounds	12.8 V	300

3. RESEARCH METHODOLOGY

In this current research, the aim being the thermal management system of lithium ion battery and while the range of the battery is from 10^0C TO 55^0C and to stay up the temperature of the battery, a heat pipe, thus being employed and also the material used for the heat pipe was copper so as the thermal conductivity of the heat pipe increases 90 times . Also it clearly points towards the fact that a heat pipe behaves as a two phase heat transfer device with a high effective thermal conductivity. Within the evaporator section, it is the input heat that does vaporize the liquid working fluid inside the wick. The liquid employed during this research are ammonia, ethylene glycol, R134a, air and water and of these the calculations are made of the output temperature of the coolants and these fluids increase the heat transfer efficiency of the heat pipe because the vapor flows towards the colder condenser section The vapor then gets condensed inside the condenser and hence gives up its heat of transformation. The condensed liquid is then returned to the evaporator by the surface action through the wick structure. The two phase flow circulation and physical change processes tend to continue as long till the temperature gradient is maintained between the evaporator and condenser.

4. DESIGN OF HEAT PIPE AND CALCULATION OF FLOW RATE OF DIFFERENT TYPES OF COOLANTS

Assumptions of heat pipe :-

1)The heat pipe operation is being administered at steady state.

2) Laminar and incompressible fluid is being employed.

3) The heat transfer through the liquid wick is modelled as pure conduction with an efficient thermal conductivity.

4) There is a bit and almost negligible temperature difference existing at the interface of liquid and vapor between the vapor core and wick structure.

5) The material of the heat pipe is copper.

6) The outer diameter of the heat pipe is considered as 3.5mm

Output temperature of different coolants.

1) Ammonia
2) Ethylene glycol
3) R134a.

Ammonia :-

1) Specific heat of the ammonia at ambient pressure and temperature = 2.2 kj/kgk
2) Density of ammonia =0.73 kg/m^3
3) Velocity of ammonia = 0.15m/s
4) Heat generation of battery =230.72 W (01)
5) Temperature of fluid Ammonia (T1)= 40^0 C (01)

Temperature of hot fluid = 40^0 C (01)

Velocity =0.15m/s

Volume flow rate = velocity x area

Now,

Volume flow rate = 0.15 [$\pi d^2/4$]

= $0.15 \times \pi \times [(3.5\times 10^{-3})^2/(4)$

= 6.80×10^{-5} m^3/s

Mass flow rate = V×D (Ammonia)

= (6.80×10^{-5} m^3/s) x (0.73 kg/m^3)

= 4.46×10^{-5} kg/s.

Now , from energy balance equation ,

Q = mCpdT

230.72= $4.46 \times 10^{-5} \times 2.2 \times (40 - T2)$

(40 – T2) = 21.1^0C

$T2= 18.9^0$ C

Output temperature of ammonia = 18.9^0 C

RI34a:-

1)Specific heat of R134a at ambient pressure and

temperature =1.44kj/kg.k

2) Density of RI34a = 4.25 kg/m^3

3)Velocity of RI34a = 1.4 m/s

4) Heat generation of battery = 230.72 W (01)

5) Temperature of fluid R134a = 40^0C (01)

Temperature of hot fluid (R134a)= T1 = 40^0C

Velocity = 1.4m/s

Volume flow rate = velocity x area

Now,

Volume flow rate = 1.4 x [$\pi d^2/4$]

= $1.4 \times \pi \times ((3.5 \times 10^{-3})^2)/4$

=$1.34 \times 10^{-6} m^3/s$

Mass flow rate = V×D (R134a)

= $1.34 \times 10^{-6} m^3/s \times 4.25 kg/m^3$

=5.72×10^{-5} kg/s

Now , from energy balance equation ,

Q = mCpdT

230.72=5.72×10^{-5} x 1.44 x (40 – T2)

(40 – T2) = 18.3

T2 =40 – 18.3

T2 = 21.7 ^{0}C

Output temperature of R134a = 21.7^0C

Ethylene glycol:-

1) Specific heat of the ethylene glycol at ambient pressure and temperature = 2.42kj/kgk
2) Density of ethylene glycol=1.11 kg/m^3
3) Velocity of ethylene glycol = 1.2m/s
4) Heat generation of battery = 230.72W (01)
5) Temperature of fluid ethylene glycol(T1)= 40^0 C (01)

Temperature of hot fluid = 40^0 C

Velocity =1.2m/s

Volume flow rate = velocity x area

Volume flow rate = $1.2[\pi d^2/4]$

$= 1.2 \times \pi \times [(3.5 \times 10^{-3})^2/(4)$

$= 5.30 \times 10^{-5}\ m^3/s$

Mass flow rate = V×D (ethylene glycol)

$= 5.30 \times 10^{-5} \times (1.11\ kg/m^3)$

$= 5.88 \times 10^{-5}\ kg/s$

Now , from energy balance equation ,

Q = mCpdT

$230.72 = 5.88 \times 10^{-5} \times 2.42 \times (40 – T2)$

(40 – T2) = 17.8

T2 =40 –17.8

T2 = 22.2 ^{0}C

Output temperature of ethylene glycol = 22.2^{0}C

5. RESULTS AND DISCUSSION

The lithium ion battery of the electric vehicle has been cooled by using a variety of coolants (ammonia, ethylene glycol, R134A) with the assistance of the heat pipe . The material of the heat pipe getting used is copper . The heat pipe also being employed so as to improve the overall efficiency of the battery as there is no need of pump or motor for the flow of coolant and in heat pipe the flow of coolant is finished with the assistance of wick inside the heat pipe. The output temperature of the water and also of the air are taken from the research paper as a reference . (01)

The result of the output temperatures of the different coolants are shown below in tabular form-

Table 04. Output temperature of different coolants

Coolant	Specific heat	Density	Velocity	Inlet temperature.	Outlet temperature.
Air	1005	1.165	13.8m/s	40^0 C	28.11^{0}C
Water	4178	1000	0.2m/s	40^0 C	33.93^{0}C
Ammonia	2.2kj/kgk	0.73kg/m^3	0.15m/s	40^{0}C	18.9^{0}C
Ethylene glycol	2.42kj/kgk	1.11kg/m^3	1.2 m/s	40^{0}C	22.2^{0}C
R134a	1.44kj/kgk	4.25kg/m^3	1.4m/s	40^{0}C	21.7^{0}C

The cooling of the battery is very important because it improves the efficiency of the battery and there are various process through which battery cooling system is done .There are various types of cooling system through which battery can be cooled. In this paper, air and various coolants are being used for cooling of the battery .The most important requirement of the efficient cooling system is that it should remove heat at a quick rate when the battery is hot and at starting the cooling system should be slow which might reduces the efficiency of the vehicle. The cooling of the battery is must necessary for a long term life. In this research the cooling of the battery takes place with the assistance of the coolant which is passing through the heat pipe. Liquid cooling system is very helpful for cooling system of the battery and in this research it is the liquid cooling being employed and using different coolants for achieving efficient cooling rates .It takes away the excessive heat which generated by the battery and saves from overheating. By using the heat pipe of copper material having 3.5 mm outer diameter that allows the coolant to flow, it reduces the heat generated .The thin steel sheets are used at the another end of the heat pipe which can help for better thermal conductivity. During this, five different coolants are being used so as to obtain different output temperatures after proper calculations , through which it can be considered which coolant is suitable for the higher cooling of the battery .

After calculating the ultimate temperature, Water as a coolant has more output temperature than other coolants . But it is not suitable to use water as a coolant because it is more prone to react with the material of the heat pipe and may later result into major problems. Thus ,Air cooling may be used for battery cooling system because the heat which is conducted at the outer parts of the battery is radiated and may well be conducted away by the stream of air. The most important advantage of the air cooling system is that its design is simple, cheaper to manufacture , needs less care and maintenance .But Indirect liquid cooling is done in this research so one cannot consider air as an coolant . So , ammonia taking as a coolant can also cause series problems as the material of the heat pipe is copper and ammonia is not compatible with copper .Thus it cannot be used in pipes having material copper and even ammonia is poisonous in high concentrations. The another disadvantage of using an ammonia is that it cannot be detected in case of leakage and it is toxic in nature . The R134a coolant has low temperature output than ethylene glycol . Therefore, the observation being that the ethylene glycol acts as a better coolant than other coolants as it has more output temperature than ammonia and R134a and even it has many advantages than other coolant. The most important advantage being that it has anti-corrosive substance which protects the coolant not to react with the copper metal. The ethylene glycol has low volatility and high boiling point and it can be easily use in winters as it is antifreeze coolant and also reduces the overheating in winters.

6. CONCLUSION

To cool the battery pack of the vehicle and for correct cooling of the battery pack, a heat pipe is employed so as to obtain the utmost efficiency of the battery. The material of the heat pipe is copper. A coolant is to be utilized in heat pipe having suitable properties. The coolant should be suitable and relevant in all conditions and also it should be most effective in dissipating the heat. Different coolants have been tested in heat pipe to test the maximum possible outlet temperature. One by one calculation of three different types of coolants was done that include ammonia, ethylene glycol and R134a. The air cooling and water cooling are being taken as a reference. Ethylene glycol is the most suitable coolant to be used in heat pipe as compared to other coolants. Ethylene glycol dissipates maximum heat and has anti corrosive properties and anti freezing properties that is acceptable in both hot and cold atmosphere. Ethylene glycol can be used in winter because of the reason that it possess anti freezing properties and it can also be used in hot conditions to avoid over-heating also.

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