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CONSTRUCTIVE AND TECHNOLOGICAL CONSIDERATIONS ON HEAT TRANSFER OPTIMIZATIONS FOR BATTERY CELL WITH PARALLELEPIPED HEAT SINKS

Luca Doru-Alexandru[1]
[1] Faculty of Mechanics Timisoara, Romania, doru.luca@student.upt.ro

ABSTRACT: The paper deals with the analysis of heat dissipation in batteries for electric and hybrid vehicles. In addition to the part of creating the model for simulating the thermal flow, the way in which the excess heat is taken over by the cooling system of the space where the battery is positioned is also considered. It should also be noted that in the final part of the work, a solution for the realization of the cooling system through additive manufacturing is proposed to ensure, on the one hand, a better heat dissipation, but also the realization of such a system with much lower manufacturing costs lower than the costs involved at this time in a ventilation cooling system or with a copper or aluminium pipe.

KEYWORDS: deposit materials, additive manufacturing, diffuse liver disorders, heat transfer, modelling materials

1. INTRODUCTION

In the first part of paper is presents the dimensioning calculation, numerical modelling as well as the thermal simulation of a heat sink, to observe the thermal behaviour. In the last part of them it is investigate the solution for cooling or heating of the car battery.

The aspects related to the thermal management of batteries keep the batteries running safely but also efficiently by regulating the boundary conditions of the temperature. High battery temperatures can accelerate battery aging and present human safety or environmental risks, and low temperatures can lead to a sudden drop in battery capacity and poorer charging or discharging performance [1].

Battery Management System is a technology based on an electronic board installed in the battery which monitors the battery, is controlling the temperature and the voltage, monitors the charge and the discharge of the cycle, protecting the battery from short circuit and overheating, improving the efficiency of the cells by extending the life of the battery [2]. The interface from the surface of heating battery and the heating or cooling element solution are presented in the Figure 1.

In the picture with blue colour is the inner cooling medium and with green is the output for them.

From the model used in Figure 1 it is possible to observe that it is important to generate a constructive solution for simulate the cooling of the surface of battery and after that in the opposite position the solution for cooling/heating of the surface of element battery.

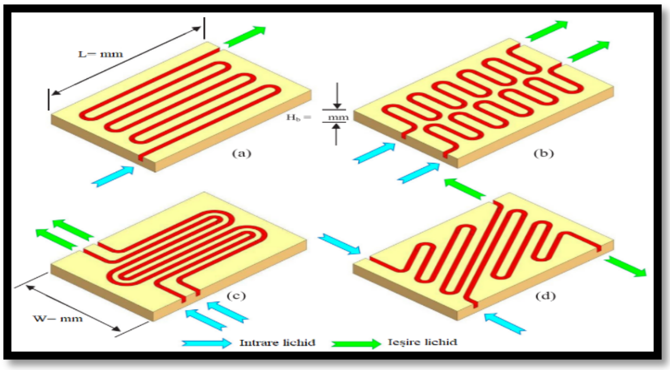


Figure 1 Examples of configurations for the boards with coil and mini-channel heat sink [1]

2. DIMENSIONIG AND SOME PHISICS ASPECTS OF GENERATED THE CAD MODEL

The importance of the phenom of heat, regarding the theoretical aspects related to heat exchange has the following modes of heat transfer:

- Thermal conduction,
- Thermal convection,
- Thermal radiation [3].

The dimensioning of the heat sink with a simple coil is starting from an analytical calculation and by calculating the channel length that interests us more in the design part and here the parameter of interest was the hydraulic diameter D_h=2.56 mm and the channel length L=1.81 m [4].

The 3D design part of the double U-coil heatsinks, and the single U-coil heatsink, for CAD solution it is used the software program named Dassault Systems CATIA V5R21.

This part of generated the solution for determining the heat transfer take in the consideration of the dimensioning of the double U-coil with the respected dimensions and symmetry Figure 2. At the same time it is important to take into consideration the dimensioning of the simple U-coil mini-channel with the respected dimensions which can be observe in the Figure 3.

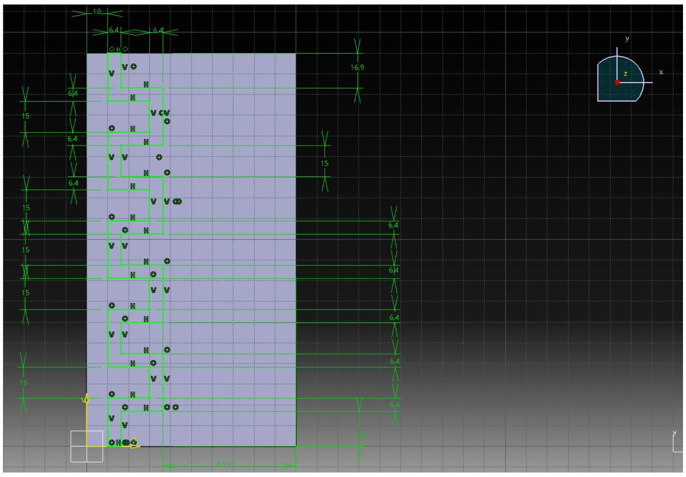
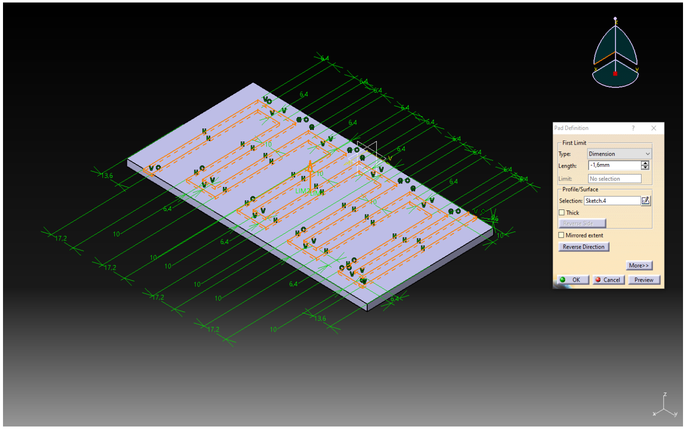


Figure 2 Dimensioning of the double U-coil with the respected dimensions and symmetry



Pad Definition
First Limit
Type: Dimension
Length: -1,6mm
Limit: No selection
Profile/Surface
Selection: Sketch.4
☐ Thick
☐ Mirrored extent

Figure 3 Dimensioning of the simple U-coil mini-channel with the respected dimensions

3. STUDY OF THE SIMULATION OF THE PROCESS

For the part regarding the simulation of the both heat sink boards, was used the Ansys Fluent software, where we are have as a basic, the two models designed in the CATIA program as *cat.part*, was created by the author of the article 5 models for 5 speed regimes for v=0.1, v=0.25, v=0.5, v=0.75, v=1 [m/s] and for each model and regime separately, I simulated the temperature of the heatsinks as well as the velocity fields.

For the simulation part of the double U-coil heat sink and the single U-coil heat sink, I used Ansys Fluent program where I had as input data, the following:

Heat flux q=5000 [W/m2].

The velocity V [m/s] of water on the input and output of the heat sinks:

- V=0.1 [m/s],
- V=0.25 [m/s],
- V=0.5 [m/s],
- V=0.75 [m/s],
- V=1 [m/s].

The temperature T [K] of the water on the input of both heat sinks:

T= 300 [K]

By changing the speed(velocity) from v=0.1 m/s to v=1 m/s, the heat flow density to q=5000 W/m^2, and the temperature to T=300 K, it is performed a calculation simulation with 200 iterations for both heat sinks. The extreme diagrams for temperature gradient and velocity fields are presented in Figure 4 for the temperature gradient of the double U-coil heatsink T_{min}=300 K and T_{max}=316 K for a flow regime of v=0.1 m/s and in Figure 5 for the velocity fields for v=0.1 m/s for the double U-coil heatsink for a flow regime of v=0.1 m/s.

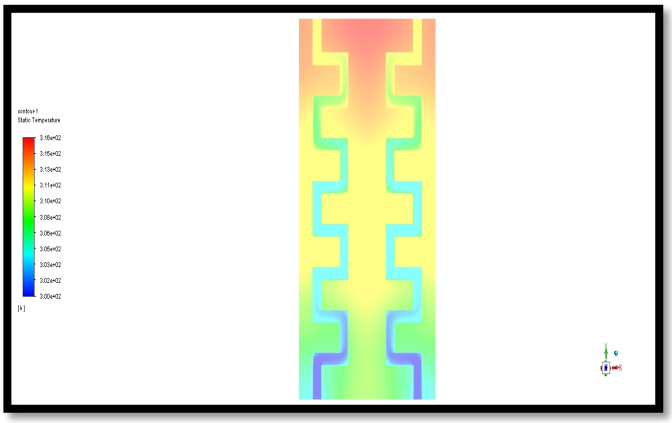


Figure 4 The temperature gradient of the double U-coil heatsink T_{min}=300 K and T_{max}=316 K for a flow regime of v=0.1 m/s

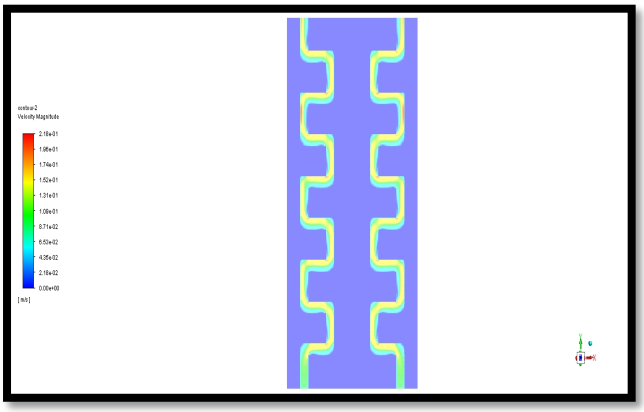


Figure 5 The velocity fields for v=0.1 m/s for the double U-coil heatsink for a flow regime of v=0.1 m/s

The quantitative results for both dissipators are referring to the thermal part, here I have taken the values from the temperature field, the pressure field, and the velocity field from a dynamic point of view.

The calculation of the thermal resistance R:

$$R = \frac{T_{max} - T_{min}}{q} \quad [K/W]$$

The quantitative result for the hydrodynamic part refers to the pressure fields taken from the data of the heat sink (the inlet/the outlet) and the pumping power.

The difference of the pressure:

$$\Delta_p = (p_{intrare} - p_{ieșire}) * 2 \qquad [Pa]$$
$$\Delta_p = (p_{intrare} - p_{ieșire}) \qquad [Pa]$$

The pumping power P:

$$P = \frac{\Delta_p * m}{\rho} \quad [W]$$

Reynolds similarity criterion:

$$Re = \frac{v * D_h * 0.001 * \rho}{\mu} \quad [-]$$

The juxtaposition of the processed data for both heat sinks, more precisely the graphic representation of the diagrams it is possible to observe that for T_{max} [K] according to the Reynolds criterion Re [-] has the tendency to increase the Reynolds criterion and it appears when decreasing the temperature variation at each speed regime Figure 6 and Figure 7. From the graphics evolution it is possible to observe that R [K/W] depending on the Reynolds criterion Re [-] the thermal resistance decreases, and the Reynolds criterion increases for each speed regime.

By analysing the previous diagrams, the thermal resistance R is influenced by the maximum temperature. Also, the thermal performance of the two heat sinks can be analysed in relation to the Reynolds criterion or the pumping power of the working fluid.

On the other hand, if the evaluation formed out, in relation to the pumping power, the two heat sinks behave the same, the difference existing only around low pumping powers. However, the uniformity of the heatsink is better in the case of the double coil variant because of the temperature gradient.

The battery profile may contain a pack of very thin rectangular plate cells. Inserts may contain a serpentine mini channel of different geometry in which the working fluid flows to cool the surface of the insert where heat is dissipated.

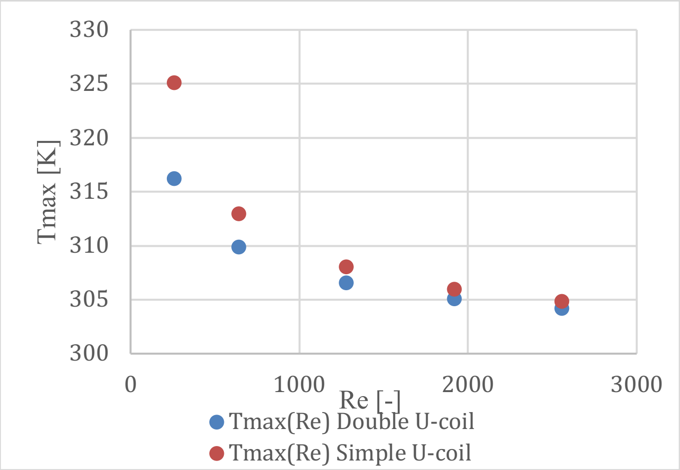


Figure 6 Maximum temperature variation T_{max} [K] as a function of Reynolds criterion [-] for double U-coil heat sink and single U-coil heat sink

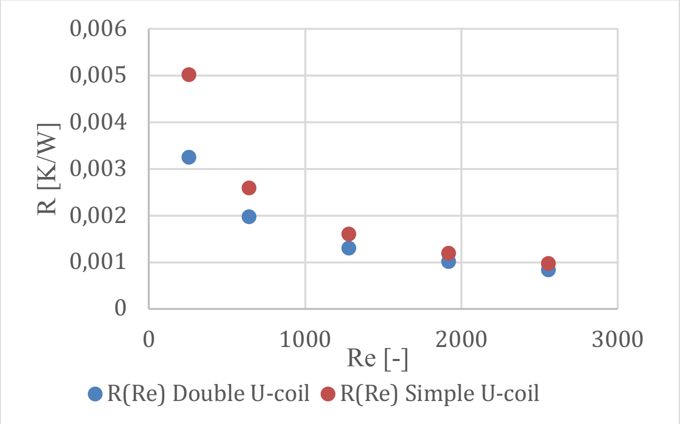


Figure 7 The variation of the thermal resistance R [K/W] as a function of Reynolds criterion Re [-] for double U-coil heat sink and single U-coil heat sink

In this example Figure 8, the heat sinks mini-channel round single-Ucoil is assumed to be homogeneous and isotropic for numerical simplification. The liquid is incompressible and constant properties, in this case is use water as a cooling liquid. The material chosen is aluminium and water will be used as the cooling liquid.

The required materials for the heat sink are aluminium due to the costs and manufacturing techniques, but for a good gradient of temperature for the scenario where the heat dissipates and for a good thermal behaviour is requested to use copper as a material.

Batteries can have an arrangement structure in series, parallel and series-parallel (mixed) configuration.

The hydraulic diameter is fixed for all configurations. The length of the total serpentine channel is the same, and the number of bends varies.

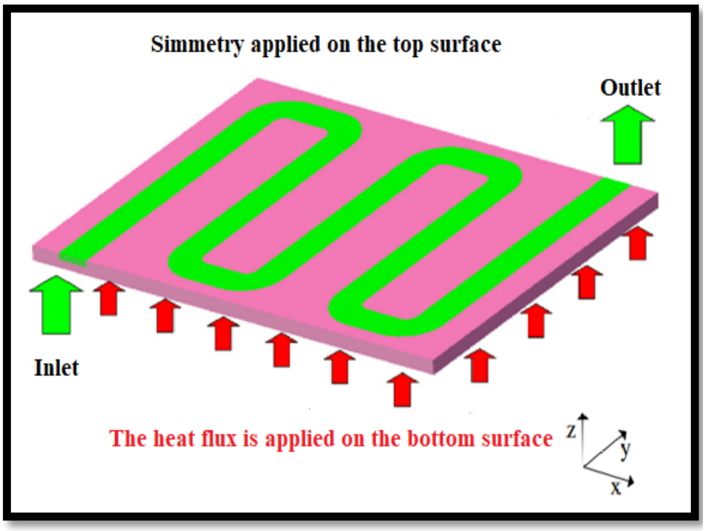


Figure 8 Single coil round U-coil heat sink (applying the heat flux to the bottom surface)

Coolant flow rate Vin and temperature T are the most important parameters of interest when simulating heat sinks in different operating regimes. [5]

Temperature equalization is used to reduce the difference of the temperature by originating inside the battery and to prevent the degradation caused by overheating of a zone from the inside of the battery.

In general, its battery can work in a temperature range of 20 °C - 35 °C, which can achieve the best output and input power of the vehicle, the maximum available energy and the longest service life.

It is important to keep in mind that using nanofluids where metal nanoparticles suspended in the base fluid result in a higher thermal conductivity than that of the base fluid.

Active solutions are composed of fans or pumps that recirculate liquid (water or other liquid) to reduce the temperature of the battery.

Passive solutions can be composed of radiators, or pipes with thermally conductive material, and which transfer heat away from the battery.

Hybrid solutions combine the key design features of both active and passive solutions.

Thermal management is the main power source of new independent energy vehicles, the importance of batteries to power new energy vehicles is obvious. In the actual use of the car, the battery will face many working conditions, the more complex but also changing.

Cruising autonomy needs to be improved, the vehicle needs to arrange as many cells as possible in a defined space, so the space for the place of the battery placed on the car is quite limited.

Due to the consistent location of the cells in the battery, it makes it very difficult to dissipate the heat in the middle area to a certain extent, which aggravates the temperature fluctuation between the battery cells.

As a result, the efficiency for the charging regime and the discharging regime of the battery will be reduced, and the power of the battery will be affected in its turn, from where it will induce a thermal escape, affecting the life span but also the safety of the entire system.

The temperature of the power battery has a great impact on its performance, duration, and safety.

At negative temperatures, the internal resistance of the lithium-ion battery will increase, and its capacity will become much smaller.

In extreme cases, the electrolyte will freeze, and the battery will not be able to be discharged. The entire low-temperature performance of the battery system will be greatly impaired, resulting in the power output performance of the electric vehicle (E.V.).

Low range when charging a new energy vehicle under low temperature limit conditions, the BMS generally heats the battery to a suitable temperature before the charging mode.

The cooling liquid in this case is water, uses a pipe that circulates coolant to reduce heat dissipation from the battery to other components. For example: Tesla company and Volt company use this cooling method. The direct cooling system of the supply battery directly uses the refrigerant (the working fluid) [6].

The rise of the temperature is due to the heat generation for the lithium-ion battery during charging and discharging directly affects the life cycle duration, reliability, efficiency, and safety of the battery. High temperature can cause heat loss of the battery walls. The recommendation to maintain the optimal temperature of the lithium-ion battery must vary from 20 °C to 40 °C and the maximum temperature difference in a battery must not exceed the value of 5 °C, being necessary to design a very adequate thermal management of the battery.

4. TECHNOLOGICAL CONSIDERATIONS ON THE REALIZATION OF THE HEAT EXCHANGER FROM RECYCLABLE MATERIALS

Although it was mentioned in the heat transfer simulation part that the heat absorption area can be made of aluminium, which is an energy-consuming material, or of copper, which also requires high energy consumption to be able to obtain the tubular product, it is worth having considering the replacement of these two materials with materials that use a reduced energy consumption for their processing and implicitly a much lower carbon footprint.

One of the modern solutions that is recommended to be considered given the observations mentioned in the previous paragraph is that of additive manufacturing. Among the additive manufacturing processes currently in use, 3D printing by optical photopolymerization with a light-emitting diode is the one that ensures, from several points of view, a good quality of both the surface and its constructive structure as much as possible observe also from the studies undertaken over time by several authors [7-12].

Considering the previously mentioned considerations, it is necessary to expand the research in the direction of determining the parameters of the optimal regime for heat transfer based on further studies, but also to expand the database by determining the optimal dimensional values for a good heat exchanger made of recyclable materials.

5. CONCLUSION

The study carried out opens new research directions that allow both a more efficient realization of the thermal energy transfer part, but also an improvement of the database and knowledge in the area of thermal transfer using materials with thermal properties close to or similar to those of non-metallic materials aluminium and copper respectively.

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