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# *Thermal Characteristics of Air Flow Cooling in the Lithium Ion Batteries Experimental Chamber*

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# THERMAL CHARACTERISTICS OF AIR FLOW COOLING IN THE LITHIUM ION BATTERIES EXPERIMENTAL CHAMBER

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## ABSTRACT

A battery pack prototype has been designed and built to evaluate various air cooling concepts for the thermal management of Li-ion batteries. The heat generation from the Li-Ion batteries was simulated with electrical heat generation devices with the same dimensions as the Li-Ion battery (200 mm × 150 mm × 12 mm). Each battery simulator generates up to 15W of heat. There are 20 temperature probes placed uniformly on the surface of the battery simulator, which can measure temperatures in the range from - 40 $^{O}$C to +120 $^{O}$C. The prototype for the pack has up to 100 battery simulators and temperature probes are recorder using a PC based DAQ system. We can measure the average surface temperature of the simulator, temperature distribution on each surface and temperature distributions in the pack. The pack which holds the battery simulators is built as a crate, with adjustable gap (varies from 2mm to 5mm) between the simulators for air flow channel studies. The total system flow rate and the inlet flow temperature are controlled during the test. The cooling channel with various heat transfer enhancing devices can be installed between the simulators to investigate the cooling performance. The prototype was designed to configure the number of cooling channels from one to hundred Li-ion battery simulators. The pack is thermally isolated which prevents heat transfer from the pack to the surroundings. The flow device can provide the air flow rate in the gap of up to 5m/s velocity and air temperature in the range from -30 $^{O}$C to +50 $^{O}$C. Test results are compared with computational modeling of the test configurations. The present test set up will be used for future tests for developing and validating new cooling concepts such as surface conditions or heat pipes.

## INTRODUCTION

Currently, the Li-ion batteries are most advanced for use in the hybrid and electrical vehicles. However, these Li-ion batteries can be used only in the narrow range of temperatures. At the temperatures above 40 $^{O}$C the life time of the batteries significantly decreases but at temperatures below 10 $^{O}$C the working characteristics and efficiency rapidly decrease. In addition the reliable thermal gradient within the battery itself and the accumulating batteries rack is limited to 5-10 $^{O}$C. That is why the temperature management of the batteries is very important for increasing the life span and for preventing expensive equipment failures.

It is shown in the publications [1,2] shown that the thermal emission of Li-ion accumulation battery depends on discharge current, volume of battery charge, depth of discharge (DOD), temperature distribution within the battery surfaces as observed in the results of IR (infra red) thermal scanning for one Li-ion battery.

One of the important issues with Li -ion battery rack is dissipation of heat generated during operation. There are several methods for cooling: liquid battery cooling (using different mineral liquids), self cooling (using thermo-conductivity of the rack frame materials, with outside air cooling them) and forced air flow cooling (in this case the applied air can be taken from outside or pre-cooled and continuously circulated in this volume). Different types of Li-ion batteries shapes and physical qualities are shown in the paper [3].

The most useful and interesting air cooling regions is in the area with low velocity air flow. If we will use these conditions we can decrease power usage of fan and volume of the sound generated by moving air in the cooling system.

We are building the experimental equipment to test the forced air thermal managing processes in battery pack containing a hundred of Li-ion battery imitators. At present time we build two battery imitators chamber for air thermal managing processes investigation. Each imitator has the same thermal conductivity, power output characteristics as expected in the original Li-ion battery [3].

## LI-ION BATTERY COOLING PROCESSES RESEARCH STATION.

The block diagram of the research station for 2-10 Li-ion battery imitators is shown on Fig.1

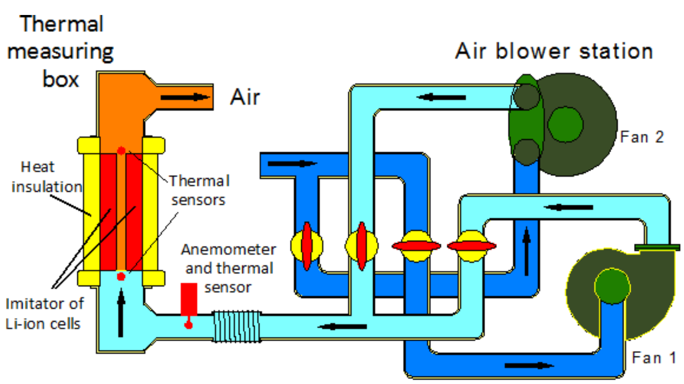


**Figure 1.** *The block diagram of the research station for Li-ion forced air cooling processes.*

The research station consist 2 main parts: air blowing station and thermo-isolating chamber. The air blowing station produce 80 ($m^3$ in hour) air, 7 Pa pressure, stabilized temperature. Additionally, we built air cooling/heating station to control the temperatures in the range from -30$^O$C to +50$^O$C. The Li-ion imitator is made of copper and dialectical plates set assembled accordingly Fig.2.

The thickness of the copper plates 3 is chosen to correspond 60W/(m•K) thermo conductivity along the outer surface. To get thermo conductivity 1 W/(m•K) through total thickness of imitator all inner and outer copper plates soldered by copper wires, evenly distributed on the surface. The heater plate 1 was built with high resistance wire. The total resistance of such heater is 60 Ohm and it generates 15 W of heat for each Li-ion imitator.

The temperature acquisition circuit plate has 20 probes, installed on the surface with 40mm distance from each other. The temperature collecting surfaces of probes after full assembling of imitator are on the outer surface. Because of these outer plates 2, 3 have 10 mm holes in front of probes. Each plate (1), (3), (4) isolated by the dialectical plate (2), to prevent short circuits.

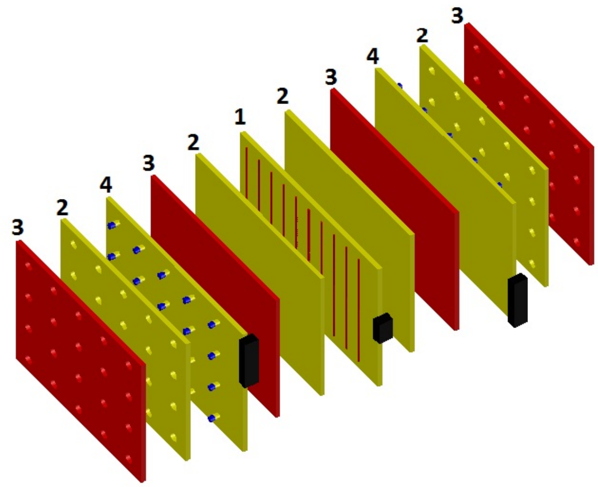


**Figure 2.** ***The Li-ion imitator design***
1 – heat generating board ,
2 – flat dialectical board,
3 – cupper board,
4 – temperature acquisition circuit plate.

All plates assembling done using thermo-conductive epoxy based glue. Fig.3 shows one of the assembled imitators.

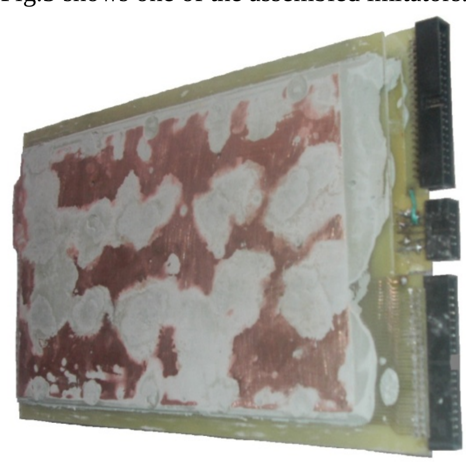

Figure 3. *The assembled imitator.*

The data from temperature probes are recorded using a PC based DAQ system, based on LCard-761 DAQ board. Before each set of experimental run, all the temperature probes were calibrated at stable temperature with the heaters off.

The pack which holds the battery simulators is built as a crate, with adjustable gap (varies from 1mm to 10mm) between the simulators for air flow channel studies. This gap space can be filling in by different medias with small air flow resistance or surfaces can be upgrade with highly complex relief to increase air cooling process of imitators.

## NUMERICAL ANALYSIS

In this section we presented the results of numerical simulation for battery imitator cooling process. SolidWorks Flow Simulation module of The SolidWorks 2011 software, providing conjugated heat transfer and flow dynamics simulation, was used. This software uses finite elements method for heat transfer in solids and finite volumes method for flow simulation.

We calculated flow parameters using three-dimensional model containing for two adjacent batteries and intermediate air gap. The model symmetry permits us to consider and apply only the half of each battery contiguous with the gap provided the corresponding boundary conditions. The final model is shown on the Fig.4.

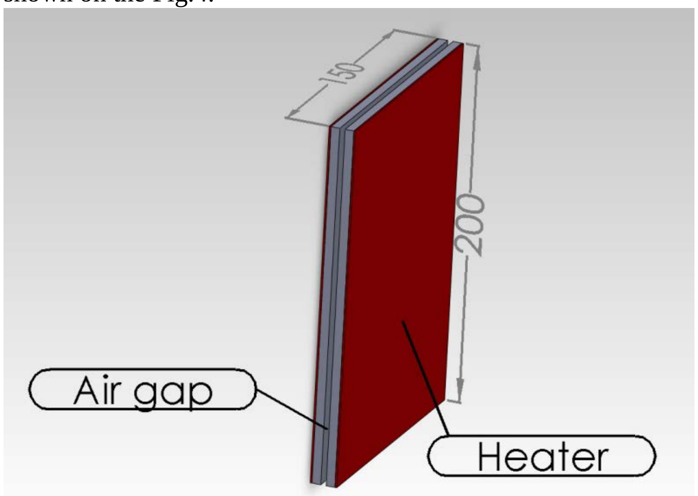


Figure 4. *Simulation geometry.*

Each battery contains heater plate (150×200×1 mm) and main plate (150×200×5 mm). Copper heater plate simulates battery heat generation volume with total heat power of 7.5 W. The main plate resembles the internal battery structure using PCB-like material with anisotropic thermal conductivity. For our model, main plate has transversal thermal conductivity of 1 W/(m•K) and longitudinal thermal conductivity of 60 W/(m•K). Calculation mesh contained 797280 cells: 342000 fluid cells, 260312 solid cells and 194968 partial cells.

The varying parameters for numerical simulation were air gap size and inlet air velocity. The primary values of interest for our studies are surface temperature distribution and pressure drop inside the gap. The examples of surface temperature distribution are presented on the Fig. 5-8.

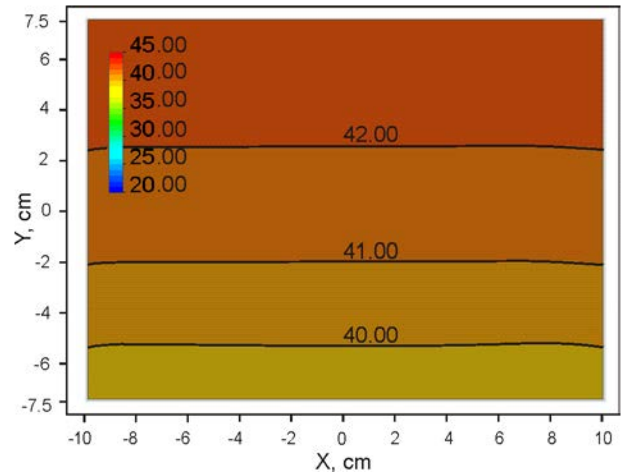


Figure 5. *Surface temperature distribution for 3 mm gap and inlet air velocity at 1 m/s.*

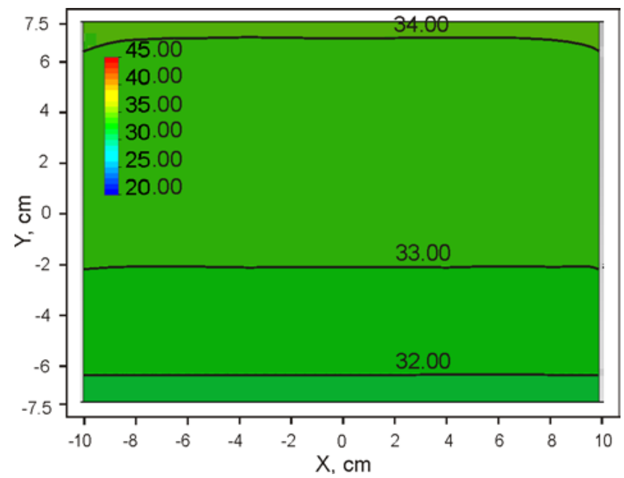


Figure 6. *Surface temperature distribution for 3 mm gap and inlet air velocity at 2 m/s.*

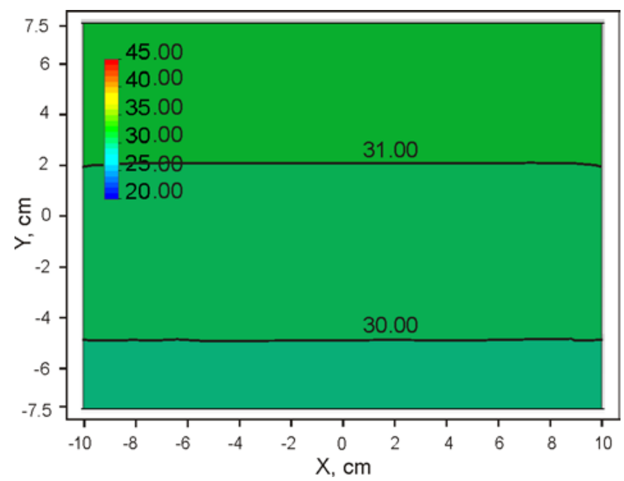


Figure 7. *Surface temperature distribution for 3 mm gap and inlet air velocity at 3 m/s.*

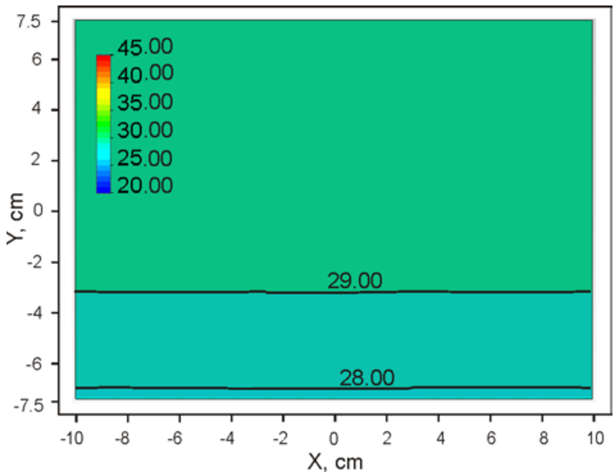


Figure 8. *Surface temperature distribution for 3 mm gap and inlet air velocity at 4m/s.*

As the cooling effectiveness characteristics we choose: Q/IDT,

where Q is thermal power output,

IDT- Inlet Temperature difference.

IDT= T(imitator) - T(air), where T(air) is incoming air temperature the space between 2 imitators, T(imitator) average temperature on the imitator surface.

T(imitator) was calculated as average from the temperature sum on the imitator surface. For experimental value of this parameter, we used measured temperature distribution for different air velocities (such as 1m/s, 2m/s, 3m/s, 4m/s) in the gaps from 2mm to 4mm.

Also, computed temperature distributions were used to predict the corresponding values of Q/ITD and compared with the experimental values.

## EXPERIMENTAL RESULTS

The experimental runs were carrying out to investigate dependency of cooling effectiveness for Li-ion batteries from the different gaps and air velocities..

During the experimental runs, the temperature on the imitator surfaces stabilized after 1.5 - 2 hours for each preset air velocities. That is why for each measurement we get the equal condition such as air velocity and stabilized temperature in 2-2.5 hours. Some of the air temperature distributions on the imitator surfaces are shown on Fig. 9-12.

The Q/ITD calculation include the instrumental error of measuring equipment and statically error for temperature averaging for thermo- probes mounting on the surface of imitator.

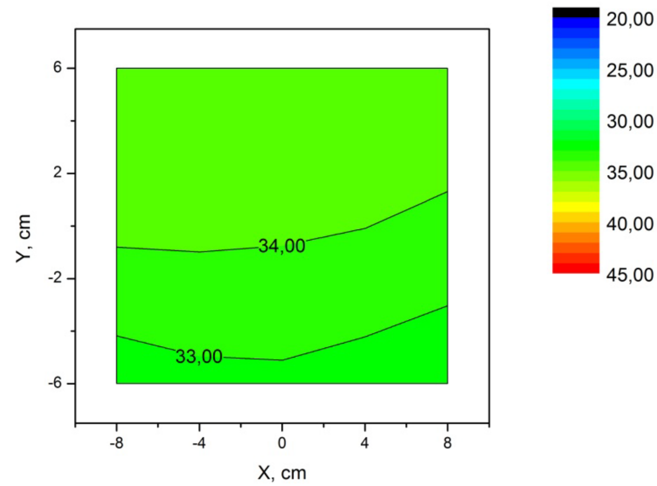


Figure 9. *Temperature distribution on the imitator surface measured at 1m/s air velocity and 3mm gap.*

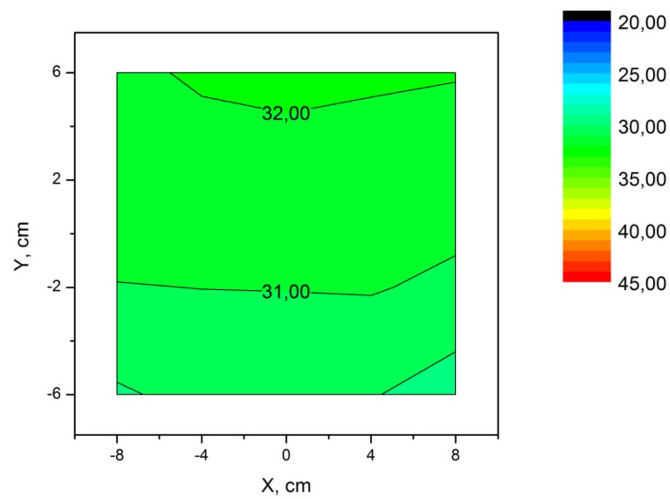


Figure 10. *Temperature distribution on the imitator surface measured at 2m/s air velocity and 3mm gap.*

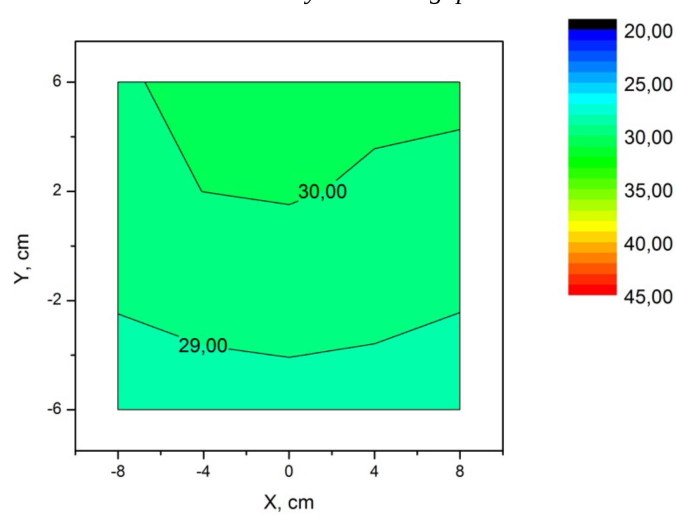


Figure 11. *Temperature distribution on the imitator surface measured at 3m/s air velocity and 3mm gap.*

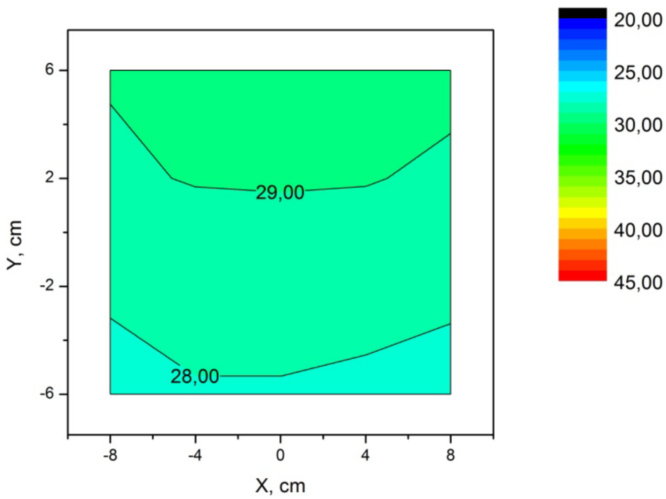


Figure 12. *Temperature distribution on the imitator surface measured at 4m/s air velocity and 3mm gap.*

Air velocity error in the gap between imitators less than +/- 3%,

measurement error for T(air) +/- 0.2 $^{O}$C,

measurement error for each thermo-probe on the imitator surface +/- 0.2 $^{O}$C, this include calibration and statically error for a hundred measurements averaging of each probe,

the average temperature error on the imitator surface is +/- 0.2 $^{O}$C,

measurement error for power output of the imitator Q is +/- 1%.

The total error for the measured Q/IDT is equal to 5%.

Fig.13 shows calculated and experimental data for Q/IDT depending of air velocity and gap between imitators.

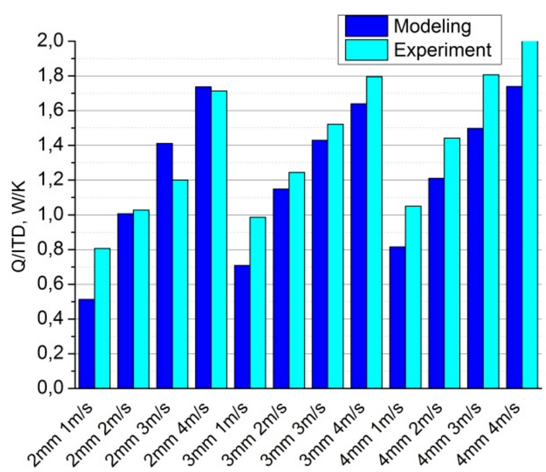


Figure 13. *Calculated and experimental data for Q/IDT.*

On Fig.14 shown calculated and measured differential pressure drops during air pass though the gap of 2mm - 4mm at 1m/s - 4m/s.

As expected the heat transfer improves with increase in velocity as reflected in increase in Q/IDT for both measurements and predictions. Similarly pressure drop increases with the increase in velocity for both measurements and analyses.

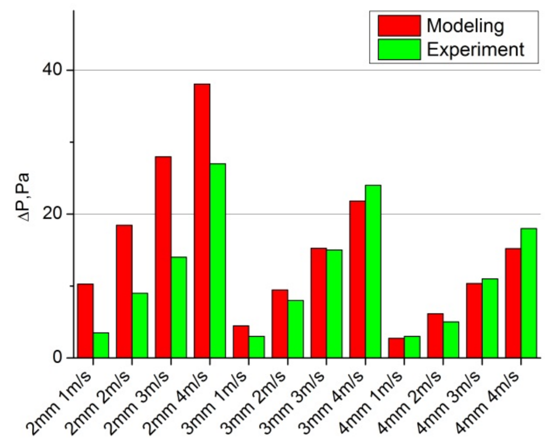


Figure 14. *calculated and measured differential pressure drops during air pass though the gap.*

All measurements were done with differential monometer instrumental error less than 10%.

## CONCLUSSIONS

This experimental measurement of air cooling process for Li-ION batteries shows good agreement with mathematical modeling of this process. There are some differences between calculated and experimental data at low air velocities.

These differences, most likely, connected to the ideal model used in the calculations. So, only heat exchange coming through the surface, adjacent to gap, were used in the calculated model, in the same time all other wall were not taken in to account, because them were considered as an adiabatic walls.

It is obvious that there will be an additional heat flows in the real experiments, which gives us low temperature values at the imitator surface and bigger values of Q/ITD.

In the future we will increase amount of imitator's elements up to 6, 20 and 100 in one complete experimental chamber. It is necessary to obtained experimental data for better air cooling management, uniform distribution of the temperatures, at the surface and inside whole volume, of the LI-ion battery.

While air flow with flat surface did provide heat rejection at reasonable temperature of below 40 $^{O}$C except foe low velocity as shown in Figure 5. We are also going to investigate different type of surfaces to get more effective air cooling processes in the Li-ion batteries and other options of heat removal such as heat pipe. The objective is to improve heat transfer with lowest air flow rate where pressure losses are less and the operation is quieter.

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