INVESTIGATION OF COLD PLATE-BASED THERMAL MANAGEMENT SYSTEM FOR LI-ION BATTERIES

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ABSTRACT
Temperature change in the battery is one of the most important parameters affecting battery performance and driving range in electric vehicles (EVs). The optimum operating performance of LIBs is achieved within a certain temperature range, generally between 15°C and 45°C. The aim of this study is to investigate a cold plate-based battery thermal management system (BTMS) that improves the EV operating performance by keeping the temperature of batteries within a desired range. The operating performance is investigated under different driving cycles. A lumped model is developed in MATLAB/Simulink to simulate the time-dependent variation in cell temperature based on the power drawn from a LIB module. The results show that cold plate improves the heat exchange from the battery. This study provides a basis for the advancement thermal management in EVs and optimization different battery geometries.

Keywords: Electric Vehicles, Battery Thermal Management, Cold Plate Technology, Li-Ion Batteries, Thermal Optimization

1. INTRODUCTION
LIBs play a vital role in electric vehicles in terms of energy supply. For them to operate with high performance, they must be within a certain operating limit. When this limit is exceeded, both performance and driving range are adversely affected. To prevent this, researchers use cold plate applications in the literature. Liu et al. (2020) examined the effects of driving conditions on the battery in their study. They observed that the driving cycle, ambient temperature, and charging rate significantly affect the driving range. They found that low-speed and low-acceleration driving can extend the lifetime of battery, while low and high temperatures can decrease it. Bhavsar et al. (2023) developed a model to regulate the temperature distribution in the battery based on probabilistic prediction of discharge current during a driving cycle. They controlled the coolant flow rate and quantity to limit the maximum temperature. Singirikonda et al. (2023) analyzed parameters such as state of charge (SOC), voltage, current, and battery temperature to calculate energy consumption under WLTP Class 3, WLTP Class 2, and NEDC driving cycles for LFP, NC, and NHM battery types in a 2018 Nissan Leaf electric vehicle. Xu et al. (2024) devised a thermal management system for Li-Ion batteries capable of operating at high temperatures and high charge/discharge rates, utilizing "S"-geometry cooling channels and composite phase change materials. Wu et al. (2024) investigated a prismatic cold plate design with variable heat transfer paths (VHTP). By altering the heat transfer path between the coolant flow and battery surface through grooves on the VHTP, they aimed to enhance cooling efficiency for cells experiencing higher temperature increases. In this study, a simplified model of a battery consisting of 14 series of 2 parallel pouch type cells is constructed and its thermal management with a spider web cold plate is investigated. The temperature change of the battery pack for three different power cycles, Worldwide Harmonized Light Vehicles Test Procedure (WLTP), Istanbul Driving Cycle (IDC) and European Driving Cycle (ECE 15), are presented.

2. METHODS
In this study, a Li-Ion Pouch Type battery module consisting of 28 cells (14 series and 2 parallel) with a capacity of 3.3 kWh was used. The technical specifications of the battery module are provided in Table 1 (Farasis Energy, 2023)

Table 1. Specification of battery cells (Farasis Energy, 2023)

Specifications	Value
Mass of battery cell (g)	505

Length of battery cell (mm)	230.5
Width of battery cell (mm)	161
Thickness of battery cell (mm)	6.16
Cell heat capacity (J kg^{-1} K^{-1})	1040
Nominal capacity (Ah)	29.3
Nominal voltage (V)	3.58
Nominal Energy (Wh)	105

In this study, parameters such as state of charge (SOC), maximum battery temperature, temperature difference within the battery, cooling effect of the cold plate on the battery, temperature difference across the cold plate, charge and discharge durations, battery capacity, operating current, operating voltage, and battery efficiency were investigated for the reference battery under WLTP - Class 1, IDC, and ECE 15 driving cycles. The battery thermal management system is modeled in MATLAB/Simulink using a lumped method. The simplified model transfers the heat generated by the battery to the air environment by convection through the four lateral surfaces and to the cold plate by conduction through the base. Power data from WLTP - Class 1, IDC and ECE 15 driving cycles are used as input data in the MATLAB/Simulink model. In the model, battery SOC status, instantaneous battery temperature, operating current, operating voltage, heat generation rate, amount of heat transferred to the cold plate, amount of heat removed from the lateral surfaces and temperature difference at the cold plate can be calculated. The studies are carried out assuming the input parameters given in Table 2.

Table 2. Input Parameters

Parameters	**Value**
Refrigerant Inlet Temperature (°C)	10
Refrigerant Inlet Flow Rate (g s^{-1})	7
Cold Plate Total Channel Area (m^2)	0.217
Ambient Temperature (°C)	25
Initial Temperature of the Battery (°C)	20
Initial SOC Value of the Battery (%)	100

The assumptions taken into account when reducing the physical problem to a mathematical model are as follows;

- Heat generation inside the battery is equal in each cell.
- The convection coefficients on the lateral surfaces of the battery module are the same.
- The heat generation in the cells does not depend on the temperature.

The top surface of the battery is assumed to be adiabatic.

$$m_b c_{p,b} \frac{\partial T_b}{\partial t} = Q_b + Q_{loss} \tag{1}$$

where, m_b is the battery mass, $c_{p,b}$ is the specific heat capacity of the battery, Q_b is the total amount of heat generated by the battery and Q_{loss} is the total heat dissipated from the battery.

$$Q_b = Q_{irr} + Q_{rev} \tag{2}$$

The heat generated inside the battery has two components, where Q_{irr} refers to the conversion of electrical energy into heat energy and Q_{rev} is related to the production and consumption during the charging and discharging processes of the battery. In the lumped model, reversible effects are ignored, and the irreversible part is defined as follows:

$$Q_{irr} = I^2 R \tag{3}$$

where I is the electrical current, and R is the internal electrical resistance.

$$SOC(t) = SOC(t_0) - \frac{\int_0^t I(t)dt}{C_{nom}} \tag{4}$$

where $SOC(t_0)$ indicates the initial state charge of the battery and C_{nom} is the nominal capacity of the battery.

$$Q_{loss} = U\, A_s\, \Delta T_{LMTD} \tag{5}$$

The term Q_{loss} expressed in Eq. (1) refers to the heat removed from the battery by conduction and convection. U is the total heat transfer coefficient, A_s is the heat transfer area and ΔT_{LMTD} is the logarithmic mean temperature difference. The outlet temperature of the cooling water from the cold plate is calculated using the equation below.

$$\frac{T_{f,out} - T_b}{T_{f,inlet} - T_b} = exp\left(\frac{-U_{ave}\, A_s}{\dot{m}\, c_{p,f}}\right) \tag{6}$$

3. RESULTS AND DISCUSSION

With the increasing use of electric vehicles, the importance of battery performance and consequently driving range has increased. The charge capacity and discharge rate of a battery are among the most important parameters affecting the driving range. To measure the performance of the battery, there are several standardized driving cycles that are globally accepted and tested. For WLTP - Class 1, IDC and ECE 15 driving cycles, current values were calculated depending on the instantaneous power requirement and used in numerical and experimental studies. Battery capacity, maximum temperature and SOC were analyzed by assuming that the initial temperature of the battery is 25 °C and the initial SOC value is 85% depending on the variable current amount. The battery temperature increased 5.05 °C because of 6138 seconds of analysis under WLTP - Class 1 driving conditions. SOC value decreased by 43%. As a result of 6138, seconds of analysis under IDC driving conditions, the battery temperature increased by 15.51°C. SOC value decreased by 55%. After 6138 seconds of analysis under ECE 15 driving conditions, the battery temperature increased by 4.03°C. SOC value decreased by 27%. SoC and temperature data are given in Figure 1 and Figure 2.

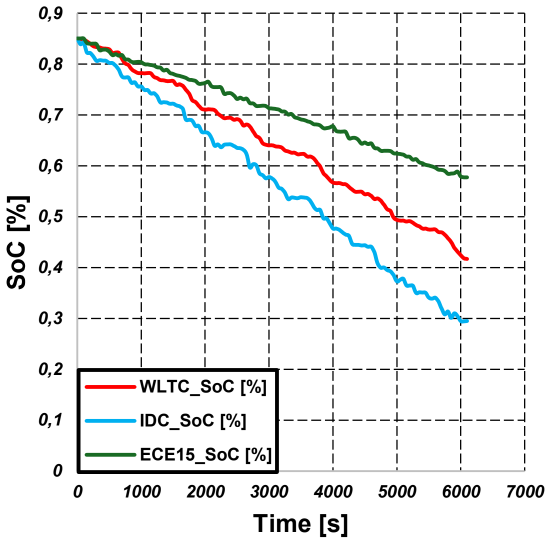

Fig. 1: Time-dependent SoC change for different driving cycles

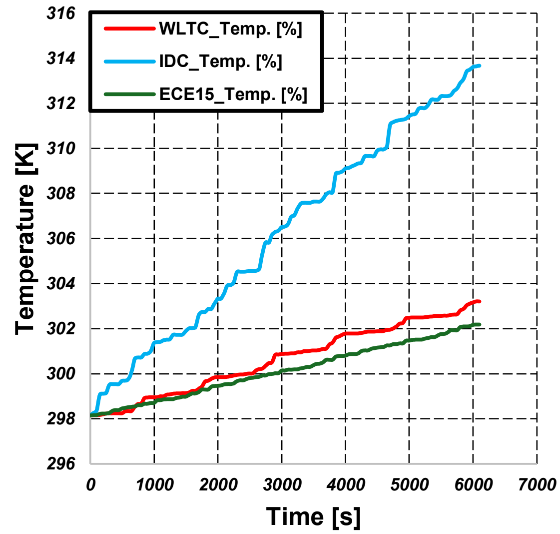

Fig. 2: Time-dependent temperature change for different driving cycles

4. CONCLUSIONS

In this study, a simplified model of a battery pack with a spider web cold plate for thermal management for different power cycles is presented. The temperature and the SOC of the battery at the end of 1000 seconds were analyzed and it was revealed that the temperature of the battery remained in range of the optimum operating temperature. In future studies, it is aimed to carry out experimental studies and compare them with numerical results.

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