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MULTI-OBJECTIVE OPTIMIZATION OF THE THERMAL MANAGEMENT OF ELECTRIC VEHICLE USING COLD PLATE TECHNOLOGY

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1. ABSTRACT

Effective thermal management systems are essential for extending the lifespan and enhancing overall performance of the Lithium Ion (Li-Ion) battery packs used in electric vehicles (EVs). Accordingly, a novel Computational Fluid Dynamics (CFD)-enabled multi-objective optimization (MOO) approach for thermal management of Li-Ion battery modules using cold plates is proposed. This is used to optimize successfully the mini-channel cold plates' geometrical parameters in terms of the key performance metrics: battery maximum temperature (T_{max}), temperature standard deviation (T_{σ}) and pumping power (P_p).

Keywords: Electric vehicles, Li-ion batteries, Computational fluid dynamics, Machine learning, Multi-objective optimization.

2. INTRODUCTION

The widespread use of internal combustion engine vehicles around the world has resulted in a number of severe environmental problems, including greenhouse gas (GHG) emissions, significant air quality degradation, and negative health effects on humans [1]. Therefore, the automobile industry is currently shifting towards more environmentally friendly and sustainable vehicles. Electric Vehicles (EVs), specifically Battery Electric Vehicles (BEVs) powered by low-emission electricity, can significantly decrease GHG emissions and improve air quality [2]. Li-Ion battery packs have recently become the most popular option for powering modern EVs. However, these types of batteries have certain drawbacks, such as high temperatures that develop as a result of chemical reactions that occur during their charging and discharging processes. These constraints create concerns about safety, thermal run-away, and sudden deterioration, with the result that efficient battery thermal management systems (BTMSs) are essential to boost the life span and overall performance. In addition, since the BTMS adds significant weight to EVs, it is important to reduce their weight as much as possible. Previous study has reported that a 10% reduction in the mass of the vehicle can result to a 5.5%-8% reduction in energy

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consumption [3]. Additionally, the reducing the vehicle's weight leads to better acceleration performance and reduced braking length [4].

3. METHODOLOGY

A novel design of a liquid-based battery thermal management (BTM) prototype, using mini-channel cold plates (MCCPs), has been developed by integrating the V-shaped intersecting bypasses into traditional serpentine channels. The BTMS layout is shown in **Fig. 1. Fig. 1a** depicts the BTMS, where each cold plate is inserted between consecutive battery cells; **Fig. 1b** shows the BTMS's bottom view; exploiting symmetry, **Fig. 1c** displays the configuration, boundary conditions and geometrical parameters (units: mm) for a half of the domain of a single battery unit and serpentine MCCP configuration with intersecting channels.

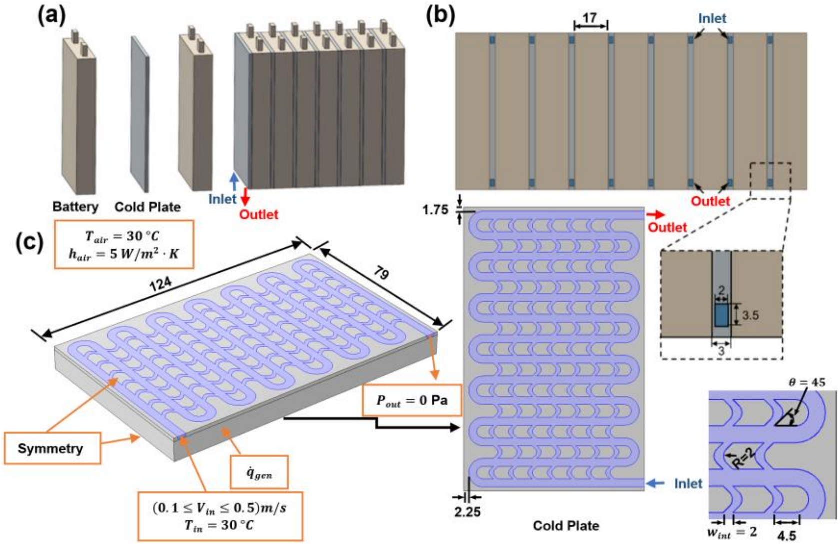

Fig. 1 The Battery Thermal Management System (BTMS).

The high fidelity prototype has been validated carefully against numerical study, see e.g. **Fig. 2**.

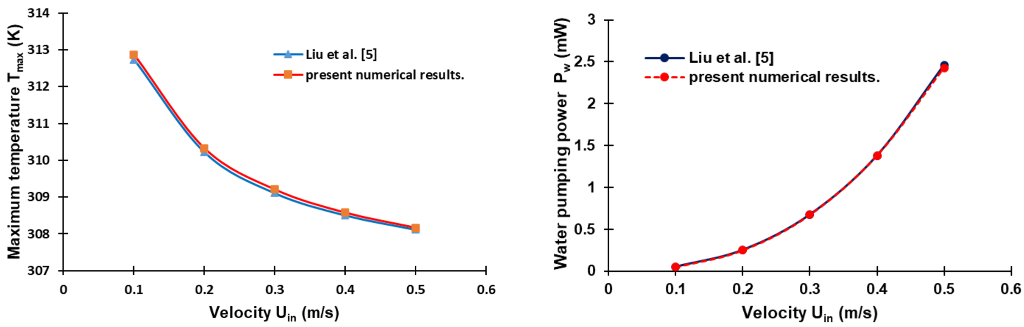

Fig. 2 A comparison between the present work's numerical results for the maximum battery temperature and water pumping power and those obtained by Liu *et al.* [5] for the MCCPs with V- shape intersected serpentine channels.

The validated model has been incorporated within a novel surrogate-enabled multi-objective optimization (MOO) methodology which can consider the influence of geometrical and operating parameters – the first time this high-fidelity BTM configuration have been incorporated with a MOO approach. This has been used in an initial optimization study to explore the influence of the cold plate’s geometrical parameters on the key performance metrics, such as battery maximum temperature (T_{max}), pumping power (P_p) and temperature standard deviation (T_σ). Four surrogate modelling approaches, using Radial Basis Functions (RBFs), Random Forests (RF), Neural Networks (NN), and Gaussian

Processes (GP), are compared to identify which approach will be selected as the most efficient for further optimization investigations. The third version of the Differential Evaluation method, known as the generalized differential evolution (GDE3) algorithm, will then use along with the selected surrogate model to perform MOO. Pareto fronts will then be generated to illustrate the potential trade-offs between all the conflicting objectives. An example demonstrating the interplay between the maximum temperature (T_{max}) and the pressure drop (ΔP) objective functions is shown in **Fig.3**.

Work is currently ongoing, using the MOO methodology to explore a wider range of geometries and operating conditions for the BTMS, taking the benefits of integrating the V-shaped bypasses in the serpentine mini-channels.

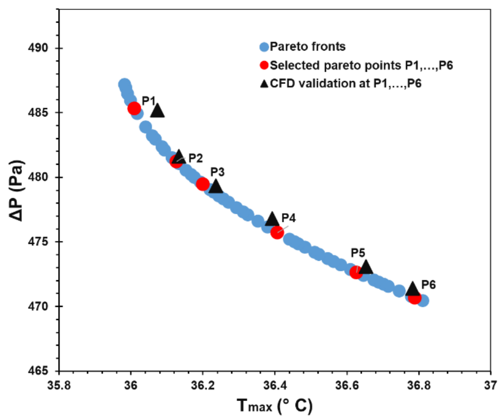

Fig. 3 Pareto curve of ΔP vs T_{max}, obtained using GP ML approach.

4. CONCLUSIONS

In this paper, a comprehensive numerical simulation and MOO methodology is developed and applied to BTMS for Li-ion battery packs in Electric Vehicles. The developed MOO methodology included of five essential steps: optimization problem formulation, input design space parameterization, design of experiments (DoEs), surrogate modeling, and the implementation of MOO algorithm. The present study employs optimal Latin hypercube sampling (OLHS) as a sampling mechanism and uses four machine learning (ML) methodologies, namely RBFs, RF, NN, and GP, for constructing surrogate models. A comprehensive analysis is conducted comparing the surrogate model profiles, and the accuracy, for each objective function, for each ML approach. The trade-offs between all the conflicting objectives will be presented using Pareto fronts, providing an extensive overview of the multi-objective optimization spaces throughout a wide range of nondominated solutions.

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