

# **Microfluidic Thermal Management for Battery Cooling: A Review on Tesla-Valve Microchannel Approach to Solve Flow Maldistribution and Thermal Non-Uniformity**

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## **Abstract**

As electric vehicles (EVs) continue to gain global market share, the thermal management of lithium-ion battery packs has emerged as a critical challenge affecting performance, safety, and longevity. Conventional air-cooling and coarse liquid-cooling systems struggle to maintain optimal temperature uniformity and dissipate high heat fluxes during fast charging and high-power discharge cycles. This report investigates a passive microfluidic approach based on Tesla-valve (valvular conduit) microchannels to rectify oscillatory or disturbed flow and enhance thermal uniformity without moving parts. Representative simulations and published data indicate that Tesla-valve cold plates can reduce peak cell temperatures and temperatures spread ( $\Delta T$ ) while maintaining comparable or lower pumping power than serpentine baselines at relevant Reynolds numbers, thereby reducing exergy destruction and improving system efficiency. The proposed methodology, optimization guidelines, and fabrication routes consolidate a path to practical EV cooling plates where passive rectification stabilizes flow distribution under real-world transients.

## **Keywords**

Battery thermal management, Tesla-valve microchannels, thermal uniformity & flow rectification.

## **1. Introduction**

The global transition toward sustainable transportation has accelerated the adoption of electric vehicles, with EV sales growing exponentially over the past decade. According to the IEA, global EV stock passed 26 million vehicles in 2022, up 60% from the previous year (Cattani et al. 2025). Such rapid growth is driven by environmental regulations (Islam 2020), improvements in technology, and falling battery costs. The performance and safety of electric vehicles are fundamentally dependent on effective thermal management; however, this is particularly critical for lithium-ion battery packs which is the primary energy storage technology for electric mobility.

## **2. Literature Review**

Lithium-ion batteries develop considerable temperature during charge-discharge cycles due to their internal resistance, electrochemical reaction, and ohmic losses. During fast charging ( $>1C$  rate) and high-power discharge, the amount of heat generated exceeds 50 W/cell, which may lead to localized temperature increases affecting battery performance (Bhattacharyya et al. 2025). Running lithium-ion cells above 45°C increases capacity fade and internal resistance while substantially reducing cycle life. For every 10°C rise above the optimum operating temperature (20° to 35°C) battery degradation rates can double (Lyu et al. 2024). Furthermore, non-uniformity in temperature through the modules of batteries-with cell-to-cell variations of more than 5°C promotes non-uniform aging and capacity imbalance, which are detrimental to safety, even thermal runaway.

Traditional battery thermal management system (BTMS) includes three approaches; air cooling, indirect liquid cooling with cold plates, and direct liquid immersion. Air-cooled approaches are simple and light in weight but lack the high heat transfer coefficient, in the range of 10 to 100 W/m<sup>2</sup>K which can hardly ensure temperature uniformity for high-density battery packages (Arshad et al. 2023). Natural convection air cooling is poor for fast-charging applications and high-performance EVs requiring sustained power delivery.

Conventional liquid cooling systems using aluminum or copper cold plates with macro-scale channels (>1 mm diameter) offer improved heat transfer (500-2000 W/m<sup>2</sup>K) but face several limitations like thermal resistance, flow maldistribution, pressure drop penalties and limited contact area (Murphy and Akrami 2024). Tesla-valve Microchannels represent a paradigm shift in battery cooling technology by leveraging microscale fluid mechanics and enhanced heat transfer mechanisms. Microchannels defined as channels with hydraulic diameters between 10 μm and 1 mm that offer several fundamental advantages such as enhanced heat transfer, temperature uniformity, compact integration and Multiphysics coupling (Huang et al. 2019; Islam 2024).

Tesla valves create asymmetric bifurcations that induce vortical mixing, hence reducing flow maldistribution and thermal non-uniformity with no active control mechanism as illustrated in Figure 1 (Lu et al. 2022). The performance of these channels are evaluated using computational fluid dynamics (CFD), solving the continuity, Navier–Stokes, and energy equations under laminar flow conditions which is typical for microchannels (Vaferi et al. 2023a).

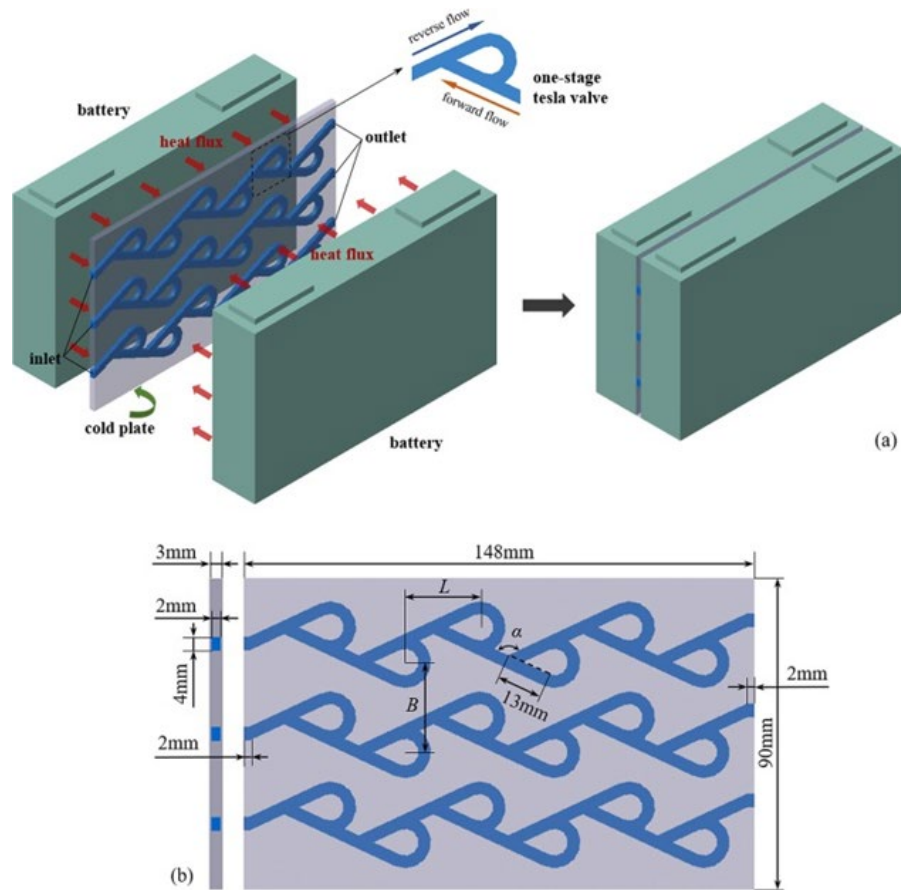


Figure 1. (a) Three-dimensional model of the cooling system, and (b) design parameters of cold plate with Tesla valve-type channels. (Lu et al. 2022)

To characterize the thermal behavior of battery cells coupled to such channels, cell heat generation is modeled by the Bernardi relation  $\dot{q}_{\text{cell}} = I(V - U_{\text{OCV}}) - IT(\partial U_{\text{OCV}} / \partial T)$ , which partitions ohmic/polarization heating and the

reversible (entropic) term (Bernardi et al. 1985). Heat transfer in the Tesla-valve channels can be quantified using the energy balance (Porwal et al. 2018)

$$\dot{Q} = hP(T_s - T_f) \text{ and } Nu = \frac{hD_h}{k}$$

where  $h$  is the convective heat transfer coefficient,  $P$  is the wetted perimeter,  $D_h$  is the hydraulic diameter, and  $k$  represents thermal conductivity of the coolant. Enhanced vortical mixing from the Tesla-valve bifurcations increases  $Nu$ , thus improving  $h$  and reducing wall temperature  $T_s$ . This enhancement translates directly into higher heat flux removal and lower  $T_{\max}$ .

The hydraulic losses can be expressed as:

$$\Delta P = 4f \frac{L}{D_h} \frac{1}{2} \rho u^2$$

where  $f$  stands for friction factor,  $L$  channel length, and  $u$  for mean velocity. Tesla-valve channels show a moderate pressure penalty ( $\sim 0.4\%$ ) for large improvements in uniformity (Hu et al. 2025). Pumping power follows  $\dot{W}_p = \frac{\dot{m} \Delta P}{\rho}$  and, together with diodicity  $D = \Delta P_{\text{reverse}} / \Delta P_{\text{forward}}$ , quantifies the hydraulic cost and rectification effect [9,14].

A second-law metric integrates these results via entropy generation  $\dot{S}_{\text{gen}} \approx \dot{Q} \left( \frac{1}{T_c} - \frac{1}{T_h} \right) + \frac{\dot{W}_p}{T_0}$  and exergy destruction  $\dot{E}_d = T_0 \dot{S}_{\text{gen}}$ ; where  $T_c$  and  $T_h$  are coolant and surface temperatures, and  $T_0$  is the ambient temperature. As Multi-Stage Tesla Valve (MSTV) reduces both  $\Delta T$  and  $T_{\max}$ , it directly lowers  $\dot{S}_{\text{gen}}$ , thus minimizing exergy loss. Moreover, the classical Darcy–Weisbach relation gives  $\Delta P \propto u^2$ , studies of Tesla-valve microchannels show a stronger nonlinear velocity dependence. Empirical fitting of CFD results reported by indicates that the pressure drop follows  $\Delta P \sim u^{7/4}$ , reflecting vortex-assisted flow and recirculation inside the valve pockets (Du et al. 2024a)

### 3. System Design and Architecture

The construction of multi-stage Tesla-valve microchannels necessitates high-precision manufacturing to maintain the curved bifurcations and branching geometry, which are key for a successful diodicity and directional flow behaviour (Mohaimen 2020). As shown in Figure 2, the valve consists of a series of looped side-chambers and angled junctions arranged to guide fluid smoothly in the forward direction while forcing recirculation and energy losses during reverse flow.

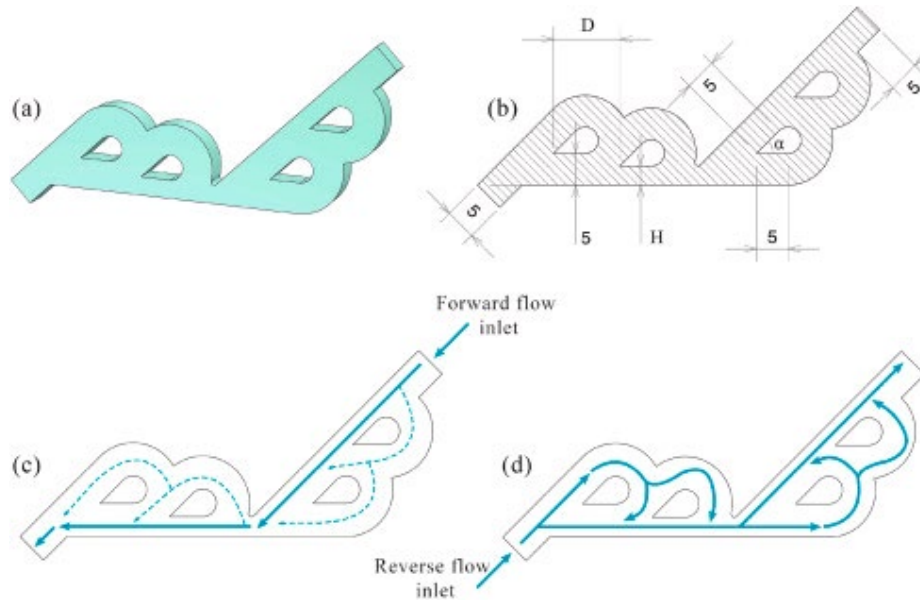


Figure 2. Precision-machined Tesla-valve microchannel layout with controlled arc and junction geometry. (a) Three-dimensional layout of the Tesla-valve microchannel; (b) structural metrics defining arc spacing and turning angles; (c) preferential low-resistance forward flow; and (d) recirculating high-resistance reverse flow (Cheng et al. 2023).

The geometry is defined by parameters such as arc spacing, channel width, and turning angle, forming a compact planar layout suitable for integration into micro-cooling plates. To fabricate these features with sufficient dimensional fidelity, high-conductivity metallic substrates, usually of either Aluminium (e.g., Al 6061) or Copper

(e.g., Cu OF), are often selected for cold-plate integration due to the intertwined interest of thermal conductivity, structural strength, and compatibility with high-pressure coolant loops (Vaferi et al. 2023b). For example, the process of CNC micromachining from Aluminum cold-plate blanks enabled a tool path specification achieving dimensional tolerances on arc radii and pocket bifurcation widths within  $\pm 10\mu\text{m}$  and allowed the proper pocket-turn geometry to achieve asymmetric resistance. (Cheng et al. 2023)

In silicon-based research prototypes, photolithography followed by deep reactive ion etching (DRIE) achieves channel depths in the range of 50–200  $\mu\text{m}$  with smooth sidewalls and high aspect ratios, facilitating micro-resolution implementation of Tesla-valve segments (Islam 2025). More recently, additive manufacturing techniques specifically selective laser melting (SLM) of AlSi10Mg or laser-powder-bed fusion of CuCrZr have been employed for complex multi-stage Tesla-valve geometries and integrated phase-change-material (PCM) cavities, allowing rapid design iteration and internal manifold embedding (Xu et al. 2024). The challenges in fabricating these microfluidic channels are maintaining strict dimensional fidelity in the turn-pocket geometry (since small deviations degrade diodicity), controlling surface roughness (roughness values above 1  $\mu\text{m}$  raise the pressure drop and diminish heat-transfer coefficient), and ensuring robust sealing and bond reliability under thermal cycling and vibration (Zhang et al. 2025). In practice, post-processing is often necessary such as polishing, electropolishing or application of corrosion-resistant coatings to reduce Ra to below  $\sim 0.8\ \mu\text{m}$  and to enhance durability under coolant and vibration exposure (Prakash and Kumar 2015). Finally, experimental validation typically encompasses both hydraulic and thermal characterization like pressure-drop measurements in forward and reverse flow directions (to determine diodicity ratio  $D = \Delta p_{\text{rev}}/\Delta p_{\text{fwd}}$ ), PIV (Particle Image Velocimetry) or micro-PIV for flow mapping in pockets, followed by thermal-bench testing under representative battery heat fluxes to confirm improved thermal uniformity and lower peak temperatures relative to conventional channel designs (Liu et al. 2023).

#### 4. Result and Discussion

As shown in Figure 3, the thermal-hydraulic performance of various MSTV Channel Designs (modeled after the MSTV) indicates that maximum surface temperature decreases steadily with increasing Reynolds Number due to decrease in convective heat removal at higher flow rates. The deepest pocket (9.40 mm) gives rise to consistently lower  $T_{\text{max}}$  values (approximately 3–4  $^{\circ}\text{C}$  lower compared with the shallowest design having 5.86 mm). The temperature uniformity index ( $T_{\sigma}$ ) follows a similar trend as  $T_{\text{max}}$ , decreasing as the Reynolds Number increases and indicating an increase in mixing and, therefore, a more uniform distribution of the coolant, resulting from the Tesla-Valve type design of the MSTV Channels.

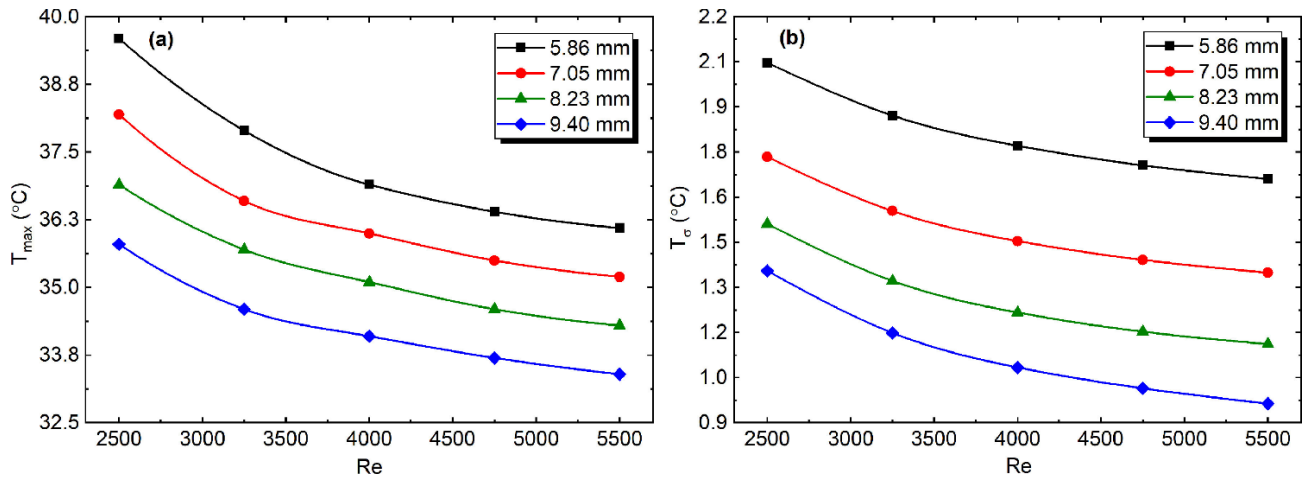


Figure 3. Relationship between Reynolds number, Nusselt number, and pressure drop for different Tesla-valve geometries, confirming the nonlinear  $\Delta P$  velocity trend and improved thermal efficiency (Monika et al. 2023).

Overall, these results demonstrate that operating at higher Reynolds numbers and employing deeper MSTV pockets are both effective strategies for lowering peak wall temperatures and improving temperature uniformity within the MSTV channel.

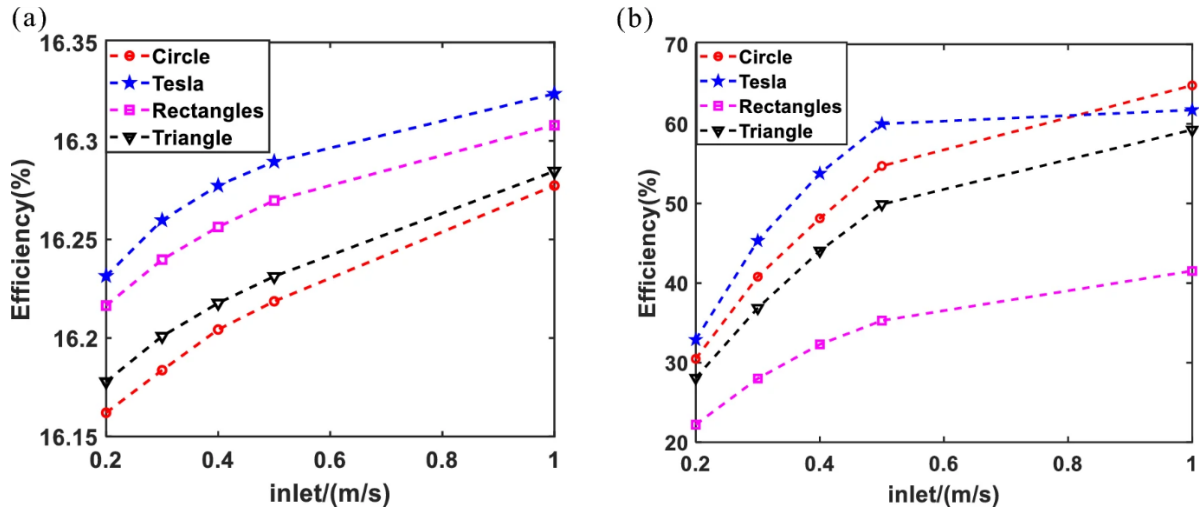


Figure 4. The thermoelectric efficiency of the four structures: (a) electrical efficiency; (b) thermal efficiency.

The energy-based efficiency is shown in Figure 4 (Du et al. 2024b), the electrical and thermal efficiency of different flow-channel geometries increases with inlet velocity from 0.2 m/s to 1 m/s. The Tesla-valve channel achieves the highest overall performance, with electrical efficiency rising from 16.18 % to 16.33 % and thermal efficiency reaching  $\approx 59.65$  %, compared to  $\approx 55$  % for circular, 50 % for triangular, and 40 % for rectangular channels. The improved performance is indeed a result of enhanced heat transfer by convection, driven by asymmetric bifurcations that stir the fluid locally and increase the Nusselt number  $Nu = hD_h/k$ . This increases the strength of the heat-transfer coefficient  $h$  while reducing the temperature gradient between coolant and cell surface—a factor directly playing into reduced exergy loss. Therefore, the MSTV channel provides a thermodynamically optimized compromise that maximizes exergy efficiency and temperature uniformity while sustaining manageable hydraulic losses.

## 5. Challenges

Although Tesla-valve microchannel cold plates show strong potential for next-generation battery thermal management, several engineering and research challenges still limit their widespread adoption. One of the primary difficulties is the high geometric sensitivity of the Tesla-valve structure. Even minor deviations in arc curvature, pocket depth, or junction width can significantly reduce diodicity and weaken the intended flow-rectification effect (Cheng et al. 2023). Maintaining such tight tolerances consistently over large cold-plate surfaces remains difficult, specifically for mass-manufactured automotive components.

Experimental and numerical studies have demonstrated that a roughness value larger than approximately  $1 \mu\text{m}$  destroys the vortical structures responsible for the enhancement in mixing, thereby increasing pressure drop and reducing heat transfer performance (Prakash and Kumar 2015). This makes post-processing steps like polishing, electropolishing, or coatings essential but adds cost and complexity.

Microchannels are inherently susceptible to clogging, fouling, and corrosion by-products, especially in long-duration of operation. Particulate contamination, coolant additive precipitation, or galvanic debris—particularly in copper-based systems—can clog the narrow passages and result in flow distribution compromise. In a similar way, the thermal cycling-mechanical vibration in EV environments can result in the induction of micro-cracks and seal degradation (Zhang et al. 2025).

It is also still difficult to predict the thermal-hydraulic behavior of multi-stage Tesla-valve networks with very transient battery loads, such as fast charging, regenerative braking, and high-burst discharge. While computationally expensive high-fidelity CFD simulations are available, simplified reduced-order models often fail in capturing strong nonlinearities associated with vortex-dominated flow (Vaferi et al. 2023b). Further research is needed to develop fast, reliable digital-twin frameworks that can adapt to rapidly changing heat-generation profiles. Finally, module-level integration brings in a set of broader engineering constraints such as—the need for robust electrical insulation, manufacturable designs compatible with automotive-scale production, acceptable pumping

power limits, and long-term durability in real-world operating conditions. Meeting these challenges will be an important part of transitioning Tesla-valve microchannel cold plates from promising laboratory prototypes to reliable, industry-ready BTMS technologies.

## 6. Promising Future

In the near future, EV manufacturers will likely adopt co-designed flow fields and battery modules, integrating manifolds, tabs, and embedded sensors into a unified cooling network so that flow rectification simultaneously balances electrochemical load. Hybrid thermal architectures pairing multi-stage Tesla-valve (MSTV) cold plates with phase-change materials (PCM) or miniature heat pipes will further buffer transient high-power charging events while maintaining minimal pumping power (Islam, 2020).

From a manufacturing perspective, progress in laser-powder-bed fusion and conformal CNC micromachining will enable tighter diodicity tolerances, embedded manifolds, and dielectric immersion-ready surfaces, while advanced post-processing (polishing, electropolishing, or functional coatings) will achieve surface roughness below  $Ra \approx 0.5 \mu\text{m}$  without erosion. On the fluid side, emerging low-viscosity dielectric coolants and nanofluid blends tuned for microscale Reynolds regimes will enhance heat capacity while resisting fouling and galvanic corrosion.

Intelligent control will move beyond fixed thermal thresholds toward digital-twin frameworks that dynamically couple electro-thermal states with thermodynamic second-law-based cost functions to minimize exergy destruction ( $\dot{E}_d$ ). These systems will autonomously adjust flow among MSTV channels via micro-valves or variable-speed pumps, while embedded pressure-temperature micro-sensor arrays monitor maldistribution and early gas evolution. Finally, sustainability mandates will drive the transition to repairable, modular cold plates, closed-loop coolant recovery, and recyclable aluminum or copper alloys, supported by emerging EV BTMS safety standards. Together, these developments will steer future EV packs toward higher power density, longer service life, and safer ultra-fast charging which will establish Tesla-valve microchannel cooling as a cornerstone of advanced electric mobility.

## 7. Conclusion

This report shows that microfluidic cooling with Tesla-valve microchannels can achieve that balance in a smarter and more sustainable way. By using the geometry itself to guide the flow rather than relying on extra pumps or active valves; Tesla-valve plates can distribute coolant evenly, prevent hotspots, and do so with very little additional energy cost. Recent advances in precision manufacturing are turning what once seemed like a lab curiosity into a practical engineering option. Technologies such as conformal CNC machining and laser-powder-bed fusion can now reproduce the delicate curves and bifurcations that make the Tesla valve work. At the same time, new dielectric coolants, phase-change materials, and nanofluid additives are improving how much heat these systems can carry away.

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## References

- Arshad, Adeel, Syed Atif Iqrar, Sol Carolina Costa Pereira, Muhammad Wakil Shahzad, Kashif Nawaz, and William Worek. "Cooling Performance of an Active-Passive Hybrid Composite Phase Change Material (HcPCM) Finned Heat Sink: Constant Operating Mode." *International Journal of Heat and Mass Transfer* 207 (June): 123973. 2023. <https://doi.org/10.1016/j.ijheatmasstransfer.2023.123973>.
- Bernardi, D., E. Pawlikowski, and J. Newman. "A General Energy Balance for Battery Systems." *Journal of The Electrochemical Society* 132 (1): 5–12. 1985. <https://doi.org/10.1149/1.2113792>.
- Bhattacharyya, Suvanjan, Shreen El-Sapa, Sumit Khatri, Nirmalendu Biswas, and Ali J. Chamkha. "Enhanced EV Battery Cooling Using Hybrid Nanofluids in Inclined Mini-Channels under Magnetic Field Influence." *The European Physical Journal Special Topics*, ahead of print, September 12. 2025. <https://doi.org/10.1140/epjs/s11734-025-01880-w>.
- Cattani, Luca, Federico Sacchelli, and Fabio Bozzoli. "Enhanced Passive Thermal Management for Electric Vehicle Batteries Using a 3D Pulsating Heat Pipe." *Energies* 18 (9): 2306. 2025. <https://doi.org/10.3390/en18092306>.
- Cheng, Peng, Xu Jianjun, Jitendra Kumar, et al. "Improving Efficiency and Optimizing Heat Transfer in a Novel Tesla Valve through Multi-Layer Perceptron Models." *Case Studies in Thermal Engineering* 49 (September): 103391. 2023. <https://doi.org/10.1016/j.csite.2023.103391>.

- Du, Shuai, Jianxin Zou, Xinli Zheng, Xin Ye, Huazheng Yang, and Ping Zhong. "Numerical Study on Solar Photovoltaic/Thermal System with Tesla Valve." *Scientific Reports* 14 (1): 10836. 2024a. <https://doi.org/10.1038/s41598-024-61785-x>.
- Du, Shuai, Jianxin Zou, Xinli Zheng, Xin Ye, Huazheng Yang, and Ping Zhong. "Numerical Study on Solar Photovoltaic/Thermal System with Tesla Valve." *Scientific Reports* 14 (1): 10836. 2024b. <https://doi.org/10.1038/s41598-024-61785-x>.
- Hu, Anjie, Rui Zhao, Dong Liu, and Yuqi Zhang. "Numerical Analysis of Heat Transfer and Multi-Objective Optimization for Tesla Valve Cold Plate." Preprint, SSRN. 2025. <https://doi.org/10.2139/ssrn.5472607>.
- Huang, Yuqi, Pan Mei, Yiji Lu, et al. "A Novel Approach for Lithium-Ion Battery Thermal Management with Streamline Shape Mini Channel Cooling Plates." *Applied Thermal Engineering* 157 (July): 113623. 2019. <https://doi.org/10.1016/j.applthermaleng.2019.04.033>.
- Mohaimen-Ul-Islam, M. , A study on diesel engine combustion. Proceedings of the 2nd international conference on industrial and mechanical engineering and operations management (IMEOM), 118-122. 2019. <https://www.ieomsociety.org/imeom/61.pdf>
- Mohaimen-Ul-Islam, M., Pollutants from inland vessels of Bangladesh-A threat to the environment. Proceedings of the 2nd international conference on industrial and mechanical engineering and operations management (IMEOM), 123-127. 2019. <https://www.ieomsociety.org/imeom/62.pdf>
- Islam, Md Mohaimen Ul. "Numerical Analysis of Particle Sorting by Acoustic Waves in Microfluidics." *BAUET Journal* 4 (2). 2024. <https://doi.org/10.59321/BAUETJ.V4I2.3>.
- Liu, Fen, Jianfeng Wang, and Yanbing Lu. "Performance Optimization of Tesla Valve Microchannel Cold Plates for Li-Ion Battery." In *The Proceedings of the 5th International Conference on Energy Storage and Intelligent Vehicles (ICEIV 2022)*, edited by Fengchun Sun, Qingxin Yang, Erik Dahlquist, and Rui Xiong, vol. 1016. Lecture Notes in Electrical Engineering. Springer Nature Singapore. 2023. [https://doi.org/10.1007/978-981-99-1027-4\\_10](https://doi.org/10.1007/978-981-99-1027-4_10).
- Lu, Yanbing, Jianfeng Wang, Fen Liu, et al. "Performance Optimisation of Tesla Valve-Type Channel for Cooling Lithium-Ion Batteries." *Applied Thermal Engineering* 212 (July): 118583. 2022. <https://doi.org/10.1016/j.applthermaleng.2022.118583>.
- Lyu, Zhipeng, Jinrong Su, Zhe Li, Xiang Li, Hanghang Yan, and Lei Chen. "A Compact Hybrid Battery Thermal Management System for Enhanced Cooling." Version 1. Preprint, arXiv. 2024. <https://doi.org/10.48550/ARXIV.2412.00999>.
- Mohaimen-Ul-Islam, M. "Acceleration Analysis of Transversely Vibrated Cracked Shafts.Pdf." *Proceedings of the 2nd International Conference on Industrial and Mechanical Engineering and Operations Management (IMEOM)*, 128–31. <https://www.ieomsociety.org/imeom/65.pdf>.
- Md Mohaimen Ul Islam. "Evolution of Cake Formation and Pressure Dynamics in Porous Microfluidic Filters." Master's thesis, Iowa State University. 2025. <https://www.proquest.com/openview/868a2478720b4cfc53c31fab04138b84/1?pq-origsite=gscholar&cbl=18750&diss=y>.
- Monika, K, U V V Phani Vivek, Chanchal Chakraborty, Sounak Roy, and Santanu Prasad Datta. 2023. "Augmentation of Multi-Stage Tesla Valve Design Cold Plate with Reverse Flow to Enhance Thermal Management of Pouch Batteries." *International Journal of Heat and Mass Transfer* 214 (November): 124439. <https://doi.org/10.1016/j.ijheatmasstransfer.2023.124439>.
- Murphy, Michael, and Mohammad Akrami. "Advanced Thermal Management of Cylindrical Lithium-Ion Battery Packs in Electric Vehicles: A Comparative CFD Study of Vertical, Horizontal, and Optimised Liquid Cooling Designs." *Batteries* 10 (8): 264. 2024. <https://doi.org/10.3390/batteries10080264>.
- Porwal, Piyush R., Scott M. Thompson, D. Keith Walters, and Tausif Jamal. "Heat Transfer and Fluid Flow Characteristics in Multistaged Tesla Valves." *Numerical Heat Transfer, Part A: Applications* 73 (6): 347–65. 2018. <https://doi.org/10.1080/10407782.2018.1447199>.
- Prakash, Shashi, and Subrata Kumar. "Fabrication of Microchannels: A Review." *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture* 229 (8): 1273–88. 2015. <https://doi.org/10.1177/0954405414535581>.
- Vaferi, Kourosh, Mohammad Vajdi, Amir Shadian, et al. "Modeling and Optimization of Hydraulic and Thermal Performance of a Tesla Valve Using a Numerical Method and Artificial Neural Network." *Entropy* 25 (7): 967. 2023a. <https://doi.org/10.3390/e25070967>.
- Vaferi, Kourosh, Mohammad Vajdi, Amir Shadian, et al.. "Modeling and Optimization of Hydraulic and Thermal Performance of a Tesla Valve Using a Numerical Method and Artificial Neural Network." *Entropy* 25 (7): 967. 2023b <https://doi.org/10.3390/e25070967>.

- Xu, Liang, Hongwei Lin, Naiyuan Hu, Lei Xi, Yunlong Li, and Jianmin Gao. "Multi-Objective Optimization towards Heat Dissipation Performance of the New Tesla Valve Channels with Partitions in a Liquid-Cooled Plate." *Energies* 17 (13): 3106. 2024. <https://doi.org/10.3390/en17133106>.
- Zhang, Yang, Dongqing Yan, Yuan Zhao, et al. "Pressure-Induced Piezoelectric Response for Mitigating Membrane Fouling in Surface Water Treatment: Insights from Continuous Operation and Biofouling Characterization." *Water Research* 268 (January): 122554. 2025. <https://doi.org/10.1016/j.watres.2024.122554>.

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