Liquid Cooling in Electric Vehicles—What to Know to Keep EVs on the Go

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Fast, efficient and accessible charging is key to the large-scale adoption of electric vehicles (EVs), particularly as people travel longer distances. Many of today's electric vehicles can travel 200-250 miles before requiring a recharge. The widespread availability of charging stations is one challenge. Charging speed is another.

Higher power (kW) used to support quicker charging generates more heat, which requires effective thermal management to achieve optimal performance. Enter liquid cooling — and the secure connections that facilitate it.

EV CHARGING IN THE FUTURE: MORE WIDELY AVAILABLE, FASTER

In 2018, there were an estimated five million electric vehicles worldwide, up two million from the previous year, according to the International Energy Agency.[1] As of late 2018, the U.S. accounted for about one million EVs.[2] In Q3 2018 alone, U.S. automakers sold 110,000 EVs — a 95% increase from the prior year.[2] The IEA projects the global number of EVs to expand to 130 million to 250 million by 2030.[1]

Among the barriers to widespread EV adoption is "range anxiety" — driver angst about finding a charging station where and when they need it, particularly for long-distance travel. This can be remedied in part by the installation of more charging stations. Today, the U.S. has an estimated 24,000 charging stations with an average of three terminals each, compared to 150,000 gas stations and approximately eight pumps per site.[3] The addition of charging stations is happening quickly, though. Volkswagen, for example, plans to invest $2 billion on charging infrastructure as part of an initiative called Electrify America that's slated to deploy roughly 2,000 chargers at over 500 sites by the end of 2019 with availability along major routes crossing 42 states.[4]

After pulling up at a charging station, drivers want to be on their way as quickly as possible. A 2019 *New York Times* article chronicled a Los Angeles-to-Las Vegas round trip of 540 miles in a compact EV that claims a 240-mile travel distance on full charge. The 13½ hour round trip required eight charging stops and 5½ hours of charging time on top of the trip's usual eight-hour drive time.[3] To optimize EV battery life, experts recommend keeping the vehicle 30% to 80% charged, so frequent charging stops are the norm.

Charging speeds also depend on compatibility between EVs and charging points. Some charge points dole out more power than a vehicle can accept. Other charge points deliver too little power relative to how quickly the vehicle can take it on. These variations are a reality in today's EV world.

Today, three main charging types exist with a fourth, faster option under exploration:

TYPE OF CHARGER	POWER SUPPLY/OUTPUT	TYPICAL CHARGING TIME
Level 1	Uses a standard 120V AC electric circuit. Output: 12-16 amps; ~1.44 kW to ~1.92 kW	8-10 hours depending on model; used for home charging 2-5 miles of range per hour of charging
Level 2	Uses a 208/240V AC electric circuit. Output: 15-80 amps[5]; ~3.1 kW to ~19.2 kW	4-8 hours; available at home and publicly 10-20 miles of range per hour of charging
Level 3 DC Fast Chargers (DCFC)	Uses a three-phase 480V AC circuit converted to direct current (DC) to the vehicle. Output: Up to 500 amps[5]; 50kW up to 350 kW	30-60 minutes 60-80 miles of range per hour of charging[6]
Next gen: Extreme Fast Chargers (XFC)	800V Output: 400kW or more	Time to charge to 200-mile range: approximately 7.5 minutes

EV HEAT GENERATION AND LIQUID COOLING

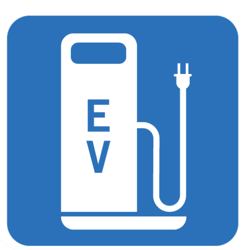
Higher power makes faster charging possible, but it also generates significant heat. The heat load for DCFC and XFC load requires advanced cooling techniques to promote safe and reliable operation. Extreme fast chargers, for example, can push battery pack temperatures to 270ºC/514ºF after just a few minutes of charging.[7] A 2017 U.S. Department of Energy report states that "the only feasible option [for cooling at XFC stations] would be to provide chilled water/coolant to the vehicle."[7]

The rate of charge is tied to the available power — a function of current and voltage. Given the inherent inefficiencies in power conversion, waste is dissipated in the form of heat. Using the power efficiency equation below, a 350kW fast charging system with a 90% charging efficiency (n) would result in nearly 40kW of dissipated waste heat.

$$P_{waste} = P_{out}\left(\frac{1}{\eta} - 1\right)$$

Existing battery thermal management systems (BTMS) are equipped to handle 1-5kW, while future generations may require upwards of 25kW or more.

Given the limitations of existing air-cooling solutions, liquid cooling is a logical next step for enabling efficient performance of onboard battery cells/packs, charging stations and other key EV components such as charging cables. All must be able to handle the heat as power increases.



- **EV charging stations:** Level 1 and 2 chargers use an onboard converter for managing power flow to the battery pack. Level 3 charging and beyond typically involves an external converter and an EVSE (EV Supply Equipment) control to safely and effectively manage the higher power loads. While the EVSE communications protocol between the charger and vehicle sets appropriate charging currents, Level 3 power convertors still need effective thermal management, which usually comes in the form of liquid cooling.
- **Vehicle battery cells/packs:** For maximum life and performance, onboard vehicle batteries must be thermally regulated during both operation and charging. Low temperatures decrease a battery's power and capacity, reducing range. Higher temperatures, on the other hand, cause accelerated degradation. Higher currents

generate more heat due to internal resistances so battery cell and pack cooling is paramount. Liquid cooling methods for battery cells and packs include conductive looped cold plates or full immersion if a dielectric fluid is deployed.

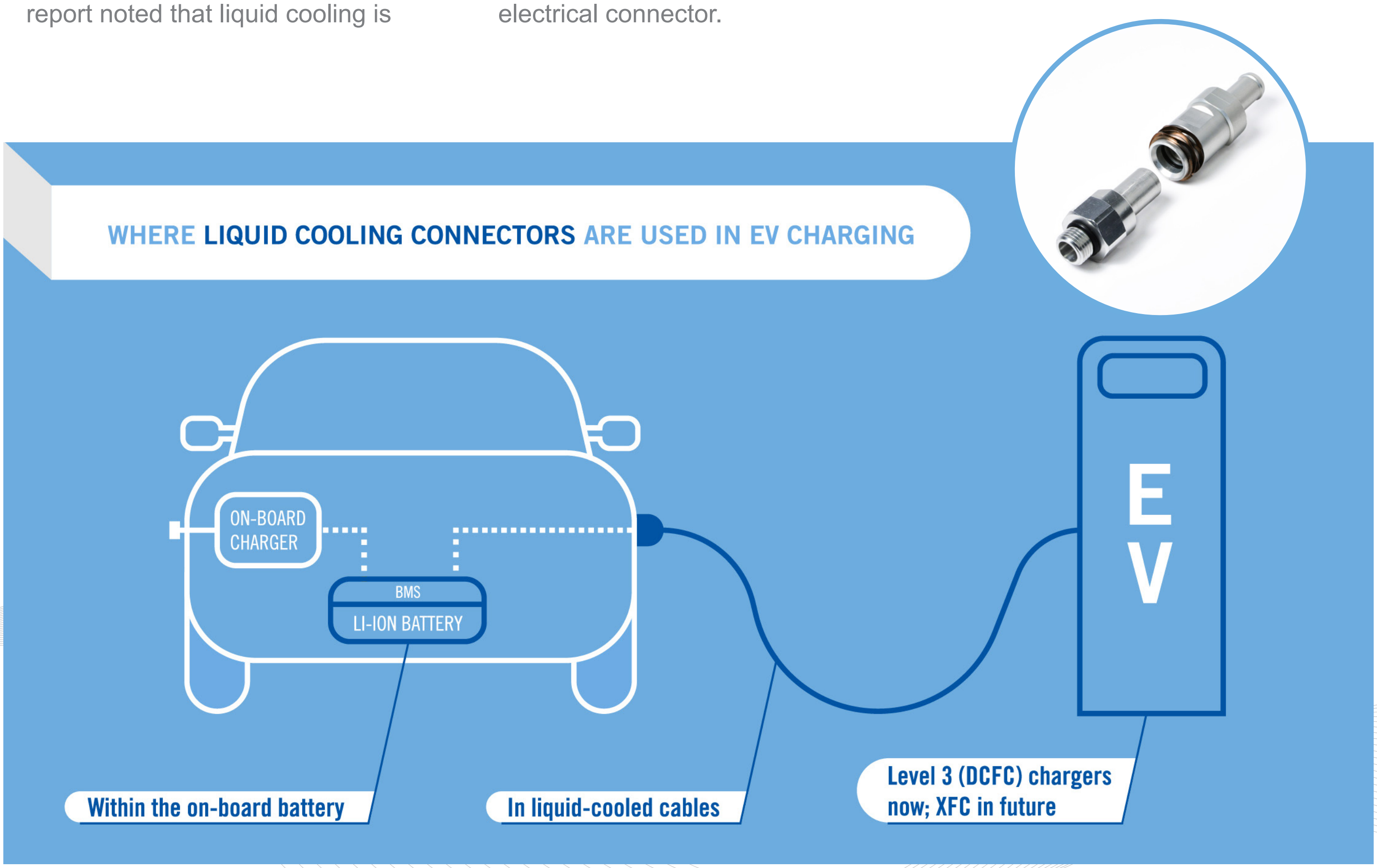
The stakes related to cooling are high, not only to ensure safe and effective operation, but also to avoid damage to equipment. When it comes to thermal design of batteries, a U.S. Department of Energy Office of Vehicle Technologies report stated: "…[EV] liquid flow channels are typically more complex and require an extensive number of connections leading to a higher potential for failure. If the liquid cooling system were to fail, then there is the potential that the liquid cooling could short out adjacent cells within the battery pack which could lead to thermal runaway."[8] The same report noted that liquid cooling is the preferred thermal management strategy for EV batteries due high heat capacity and thermal conductivity. So liquid cooling is critical — as is the robustness of the connectors within the cooling system.

- **Charging cables:** Kilowatt maximums with wiring and electrical connectors present a technical limitation as charge rates increase. A DC fast charger necessitates larger conductors. As charging speed and the associated heat increases, the cables would become bulky and cumbersome. Liquid cooled charging cables can use thinner-gauge wire and reduce cable weight by 40%[9] — and lighter-weight cables are easier for consumers to handle. Some technologies already offer liquid cooling that lowers the temperature in the charging cables and at the DC contacts at the vehicle's electrical connector.

OPTIMIZING LIQUID COOLING — FLUID CONNECTOR CONSIDER-ATIONS

Well-designed fluid connectors used in EV and EVSE liquid cooling will:

- Be purpose-built for liquid cooling applications, whether off-the-shelf or custom products.
- Meet or exceed fluid compatibility, flow, pressure and temperature performance needs.
- Withstand applicable environmental operating conditions — e.g., a wide range of temperatures, exposure to moisture, dirt/dust, and vibration in the case of connectors used with vehicle batteries.
- Avoid leaks — a robust seal design must tolerate installation and use pressures (side load, flexing, tensile forces) without compromising the



seal thereby exposing expensive and crucial components to fluids.

- Maintain performance for long periods of connection.
- Offer reliable, reproducible performance and associated validation reports.

In specifying connectors for EV/EVSE liquid cooling applications, the following characteristics and performance parameters are useful in ensuring the components will function optimally relative to overall system requirements.

PERFORMANCE CHARACTERISTIC	DESCRIPTION AND ASSOCIATED CONSIDERATIONS
Connector Type Consider space constraints, required force-to-connect, ease of use, and ability to confirm a secure connection along with other baseline performance parameters like pressure, flow and durability.	
Quick disconnects (QDs)	Used for points of connection in liquid cooling; have drip-free performance with seals and internal valves that can handle the pressure, flow, chemical compatibility and operating conditions of EV applications including swappable battery packs; integrated battery packs/cells on board the vehicle; and, EV charging station power inverters.
Latched	Integrated thumb latches eases connection/disconnection by allowing one-handed operation; audible “click” confirms full connection
Blind mate	Requires a separate retention mechanism, such as a separate latch; releasing force disconnects the QD; good option for difficult to see/access locations
QDs with elbows, swivel joints	Integrated swivel joints and elbows eliminate tube kinking and allow easier connection and disconnection in tight spaces by orienting latches for easy access
Connector Materials Consider chemical compatibility, materials in contact with coolant (wetted materials like valves, seals, connector body), pressure, temperature, reliability, weight	
Metal	Durable, withstands rough handling, susceptible to corrosion — coolant system maintenance critical for lasting leak-free performance
Polymer	Lightweight, compact, allows unique geometries for flow path; usually less expensive than metal, engineered polymers offer more than sufficient strength and durability in low-pressure (<200 PSI), moderate-temperature (<80°C) applications; good flame retardance — seek materials that adhere to UL94-V0
Combination: metal/polymer	Combines the strength of a metal exterior with high-performance engineered polymer components inside; the rugged exterior withstands physical abuse while robust engineering-grade thermoplastics resist corrosion and optimize flow
Coolant type	Chemical compatibility across wetted materials is critical. When conductive fluids such as water or glycol/water are present, use of dissimilar metals should be avoided to prevent risk of galvanic corrosion. Polymeric components such as elastomeric o-rings, tubing, or thermoplastic connectors should be selected based on compatibility with coolant. Certain dielectrics and refrigerants may warrant special consideration with regard to compatibility.

Flow Rate, Pressure and Pressure Drop Consider flow rates required in cooling the various components within EV (e.g., onboard batteries, EV charging station power inverters)	
Flow rate	Because heat transfer capacity is related to fluid mass flow rate, high-flow connectors must also maintain low pressure loss to improve efficiency. Coolant flow rates vary based on the managed heat load, fluid type and cooling system type. Considering these variables and the connector's location in the system, volumetric rates (Q) could be $0.25 \leq Q \leq 10$gpm. Flow rates that exceed the connector's maximum flow rate capacity can lead to seal failure or accelerated part erosion.
Connector size	Specify appropriate connector size(s) — equivalent hydraulic diameter. Onboard cooling loop connector sizes typically range from 1/8" to 1/2". EV fast charging station cooling systems may require 1/2" or larger connections to support higher flow capacity. Look for quick-disconnects with optimized flow coefficients to help reduce pressure drop through the connector and cooling system burden; also consider physical space available to ensure adequate room for connections, disconnections and ongoing use.
Pressure	Operating, surge and burst pressures should all be assessed. Operating pressure defines the usual and customary pressure ranges during regular system use. Burst pressure indicates the point at which a component no longer maintains pressure, generally paired with a mechanical failure. Surge pressure can be useful in characterizing runaway scenarios or extreme environmental conditions such as thermal cycling during shipment. Pressure relief mechanisms may be incorporated into the cooling system or the quick-disconnect itself to mitigate risk of over-pressurization.
Pressure drop	Both flow rate and connector size affect pressure drop; calculate pressure drop throughout the cooling system. To calculate the pressure drop for a given flow rate through a QD, use the following equation: $$Q = C_v \sqrt{\frac{\Delta P}{SG}}$$ **Q =** volumetric flow rate in gallons per minute **Cv =** flow coefficient of the connector* **ΔP =** pressure drop in PSI (Δ between the upstream pressure and the down¬stream pressure) **SG =** specific gravity of fluid **Published values for Cv are typically related to water. If necessary, apply correction factors for specific coolant used.*
Stop-flow/Dripless Performance Consider the level of tolerance for coolant escape at disconnection. Materials, seals, valve type and overall connector design impact the level of coolant present at disconnection.	
Straight-through connectors	Neither connector half features a valve arresting flow prior to disconnection
Single shut-off valve	One side of the QD contains a valve to arrest flow
Double shut-off valves	Both QD halves contain valves; poppet valves trap a small amount of liquid within the coupling body that can drip when disconnected
Flush-face valves	Most dripless/dry break/non-spill QDs feature flush-face valves that allow no more than a coating of coolant on valve surfaces

Connectors should be tested to ensure functionality and performance specific to the defined application requirements. CPC offers transparency regarding test methods and results for its liquid cooling connectors through validation reports available from CPC or an authorized distributor.

The CPC team applies its extensive knowledge in thermal management to create durable, purpose-built liquid cooling connector solutions. Customers in EV and other categories using liquid cooling rely on CPC engineering expertise to ensure their products and systems deliver long-lasting, efficient, leak-free and reliable performance.

With a broad range of solutions including custom products, CPC connectors handle the requirements of even the most demanding applications. For more information visit: cpcworldwide.com/liquid-cooling. Or contact one of our thermal management/liquid cooling engineers at: Ask Our Engineers.

References

1. IEA (2019).Global EV Outlook 2019. IEA, Paris, Retrieved at: https://www.iea.org/publications/reports/globalevoutlook2019/
2. Joselow M. The U.S. has 1 million electric vehicles, but does it matter? Sci Am. (2018.) Retrieved at: https://www.scientificamerican.com/article/the-u-s-has-1-million-electric-vehicles-but-does-it-matter/
3. Penn I. Las Vegas and back by electric car: 8 hours driving; 5 more plugged in. New York Times. June 22, 2019. Retrieved at: https://www.nytimes.com/2019/06/22/business/energy-environment/electric-cars-charging.html
4. About electrical vehicle charging. Electrify America. Retrieved at: https://www.electrifyamerica.com/about-ev-charging
5. Chon S., Bhardwaj M., Nene H. Maximizing power for Level 3 EV charging stations. Retrieved at: http://www.ti.com/lit/wp/sway014/sway014.pdf
6. California Energy Commission. (Jan. 2018). Electrical vehicle charger selection guide. Retrieved at: https://afdc.energy.gov/files/u/publication/EV_Charger_Selection_Guide_2018-01-112.pdf
7. U.S. Dept. of Energy/Office of Energy Efficiency and Renewable Energy. (Oct. 2017). Enabling fast charging: A technology gap assessment. Retrieved at: https://www.energy.gov/sites/prod/files/2017/10/f38/XFC%20Technology%20Gap%20Assessment%20Report_FINAL_10202017.pdf
8. Keyser M. et al. Enabling fast charging—battery thermal considerations. J. Pow Sour 367 (2017) 228-236. Retrieved at: https://www.osti.gov/servlets/purl/1408689
9. Cooper L. Liquid cooling tech used in high power charging solution for EVs. Electronic Specifier. (Jan. 9, 2018). Retrieved at: https://automotive.electronicspecifier.com/power/liquid-cooling-tech-used-in-high-power-charging-solution-for-evs

For more information, visit: cpcworldwide.com/liquid-cooling.

Contact CPC at: marketing@cpcworldwide.com.

Or by contacting one of our liquid cooling engineers at: Ask Our Engineers.

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