Design and Testing of EV Liquid Cooling System

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Overview

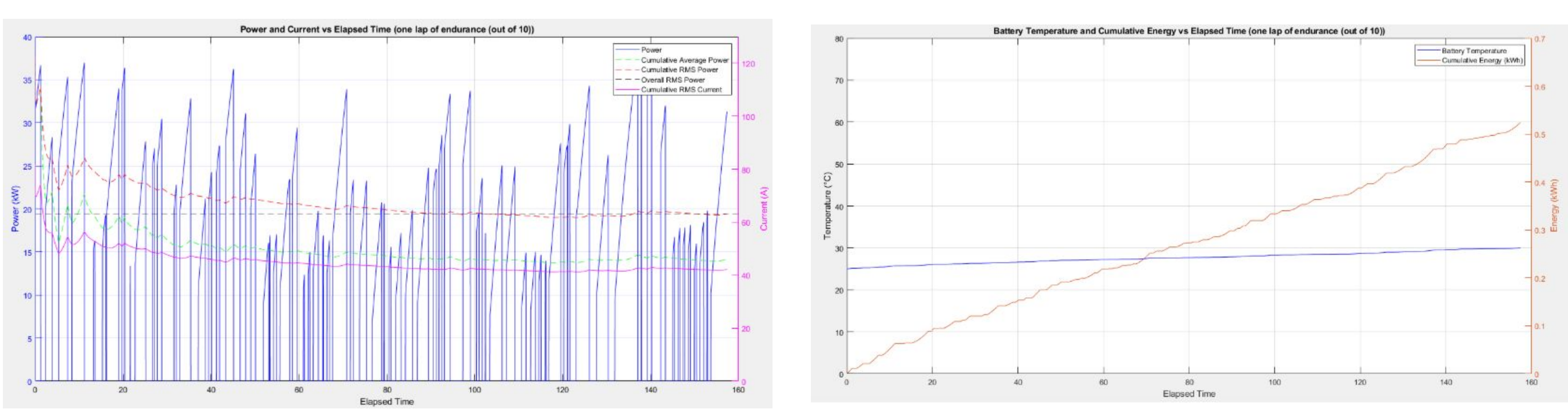
With demand for electric vehicles on the rise, an important challenge to address is thermal management of the heat generating components. As with much of the automotive industry, new concepts are developed on the racetrack prior to being implemented into production cars. This project is on the development of an effective cooling system for a formula student electric vehicle though innovative heat exchanger designs.

Methods

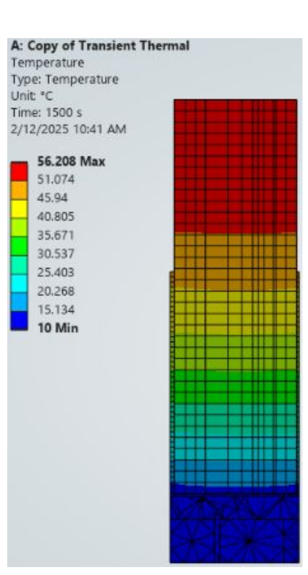
The cooling system consists of three heat exchangers: battery cooling plates (QTY 5), inverter cooling plates (QTY 2), and motor cooling sleeves (QTY 2). The heat exchangers were designed using 3D CAD software. To guide the cooling system design, thermal and fluid simulations were conducted on various computer programs along with hand calculations to verify the results.

After optimizing the heat exchangers based on simulation results, the heat exchangers were manufactured. These heat exchangers were then tested to find optimal mechanical configurations (flow rate, pressure drop), ensuring adequate sealing of the liquid cooling components is achieved, and to characterize the exchangers thermally.

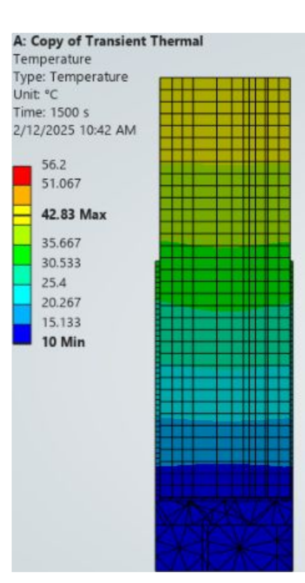
Lap simulation to dictate heat generated from components



AlN Fin Effectiveness Simulation



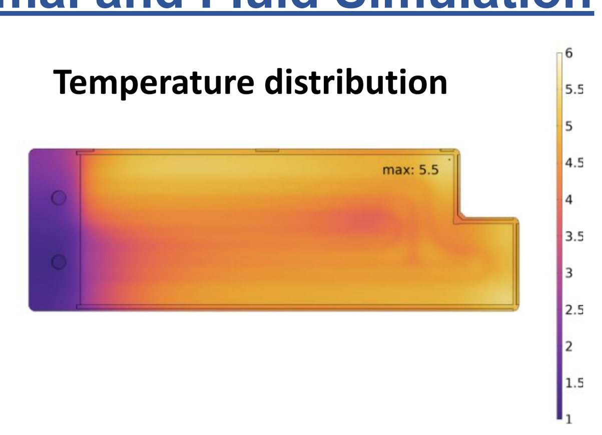
Potting Compound



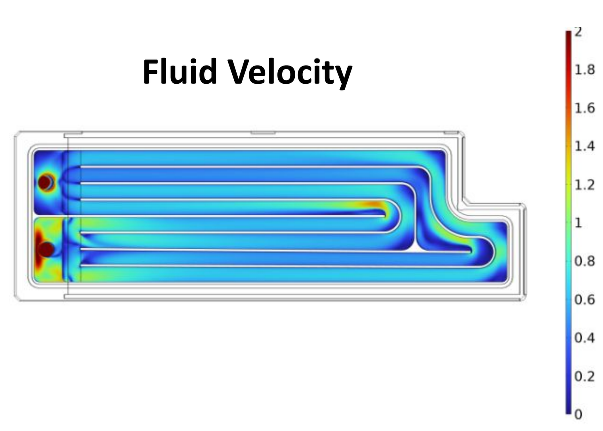
Aluminum Nitride Fins

Thermal and Fluid Simulation

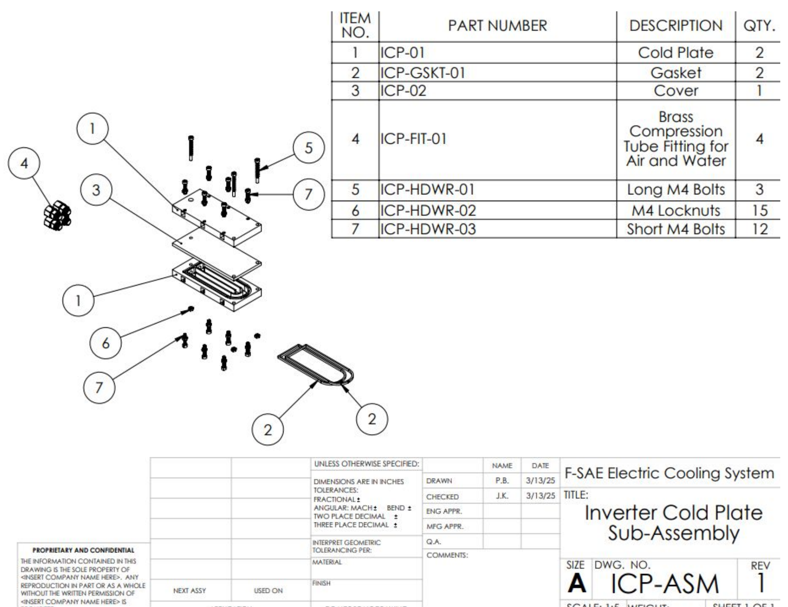
Temperature distribution



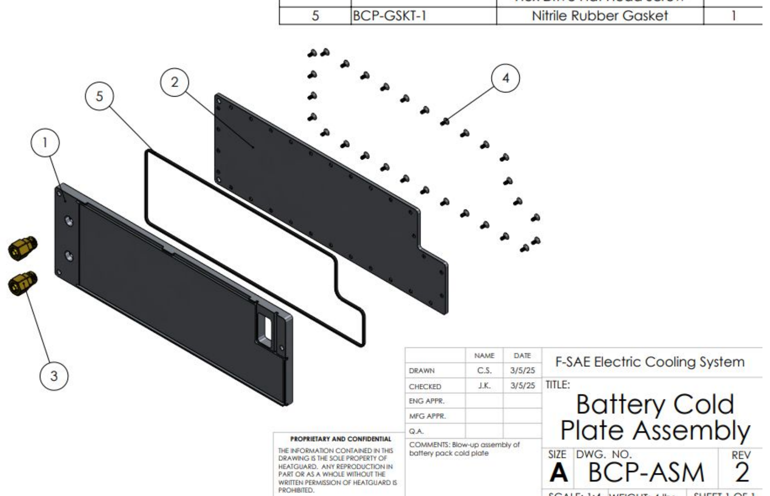
Fluid Velocity



3D CAD Assemblies of Heat Exchangers

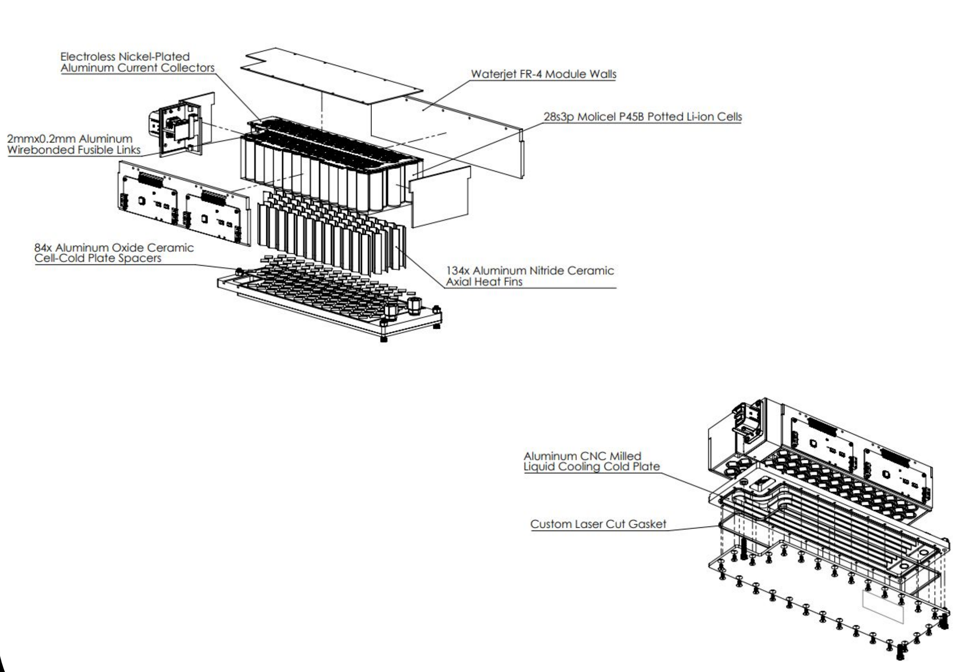


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	ICP-01	Cold Plate	2
2	ICP-GSKT-01	Gasket	2
3	ICP-02	Cover	1
4	ICP-FIT-01	Brass Compression Tube Fitting for Air and Water	4
5	ICP-HDWR-01	Long M4 Bolts	3
6	ICP-HDWR-02	M4 Locknuts	15
7	ICP-HDWR-03	Short M4 Bolts	12

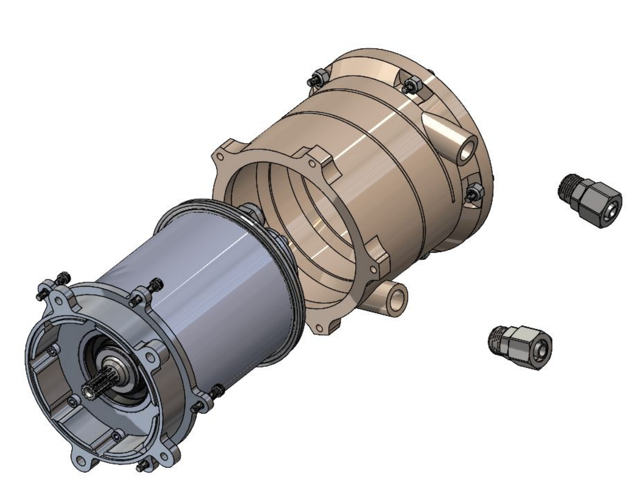


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	BCP-1	Plate in contact with batteries	1
2	BCP-2	Sealing Plate	1
3	BCP-FIT-1	Brass Compression Tube Fitting	2
4	BCP-HDWR-1	3/8" 8-32 Zinc-Plated Alloy Steel Hex Drive Flat Head Screw	29
5	BCP-GSKT-1	Nitrile Rubber Gasket	1

Battery Module with Cold Plate



Motor Cooling Jacket

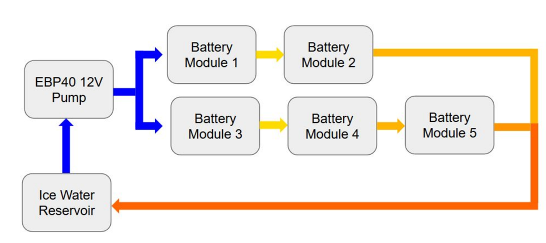


Results

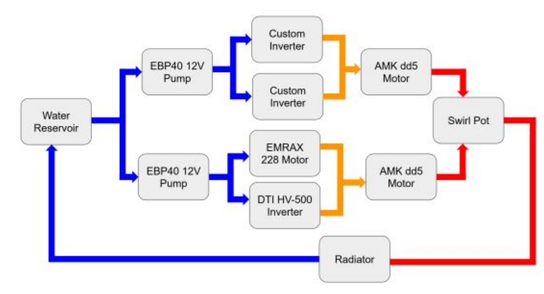
The results of bench testing the heat exchangers proved that they did not leak and allowed for the optimal configuration to be determined. Ultimately, two separate cooling loops were decided upon for the cooling system. One loop for the batteries and another for the motors and motor controllers (inverters). These loop configurations can be seen in the figures below. For the battery cooling loop, a configuration of 2 and 3 in series both parallel with each other was determined reaching a flow rate of 1.35 GPM at 60 W of input power. The plates were also proven to have an average heat transfer coefficient of 1,630 W/m^2K which results in an estimated 23% increase in the maximum power the vehicle can run at during the endurance race while remaining below its thermal limits.

Cooling Loops

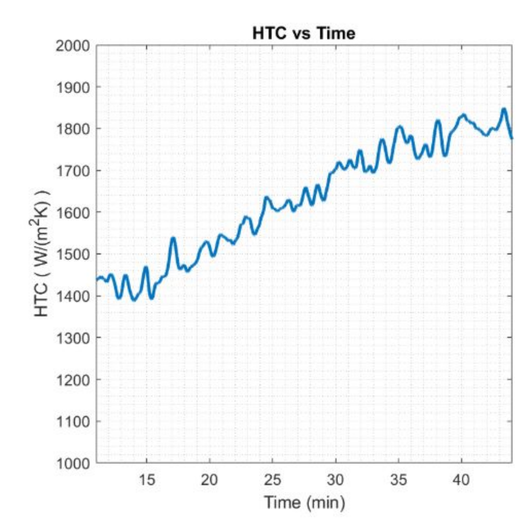
Battery Cooling Loop

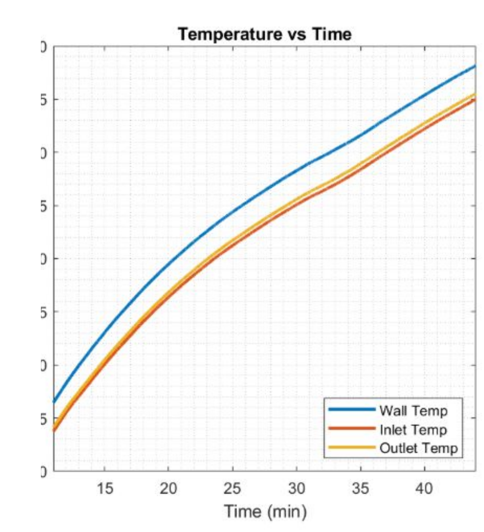


Motor/Inverter Cooling Loop

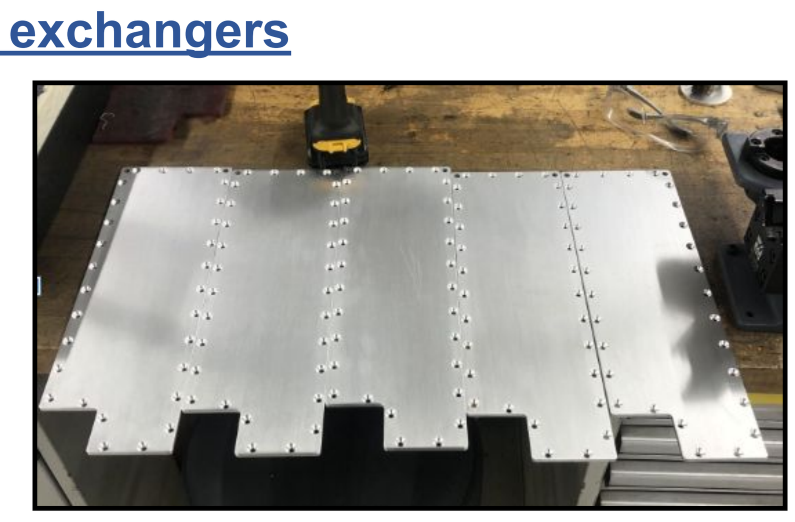


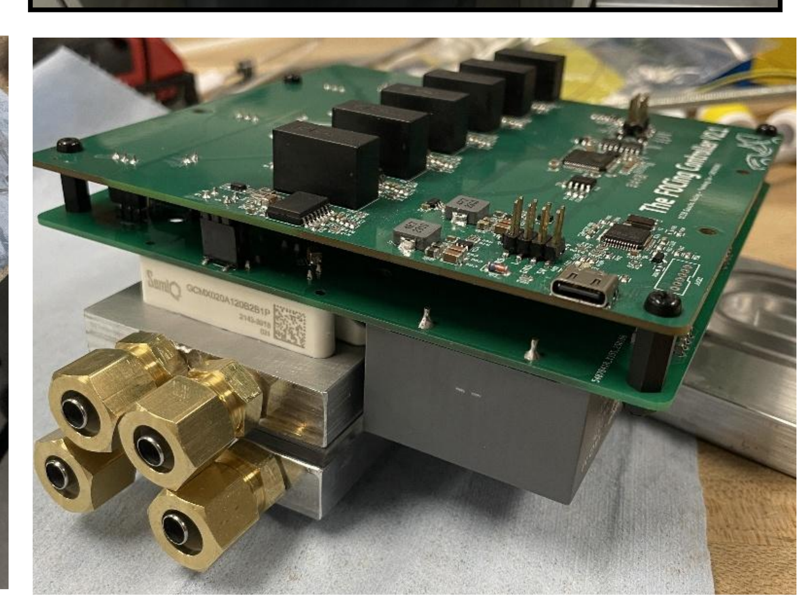
Thermal Characterization





Completed Heat exchangers





Bench Testing Fixture

Discussion

From the simulation data, thermally conductive electrical insulation (Aluminum Nitride) was pursued to promote a more uniform temperature gradient in the battery cells. Simulations dictated that the manufactured cooling system improved the vehicle's ability to drive for a longer distance before overheating by a significant amount compared to without. UCSB's Formula SAE electric vehicle team will be implementing these heat exchangers into their 2025 vehicle. That vehicle will compete in an endurance test in Michigan this summer which is the most thermally demanding event of the competition in Michigan.

Acknowledgements

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