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Original heat exchanger design for additive manufacturing

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Introduction

The aim of this work was the design of a new type of heat exchanger (HX) that can replace a shell and tube one mounted on a Computer Controlled Heat Exchanger Service Module developed by Armfield. The design was driven by the opportunities offered by additive manufacturing, mainly realizing nonstandard challenging geometries for the heat exchanger core.

Starting with the analysis of the elementary core cell, an original ultra-compact heat exchanger was designed, numerically tested and preliminarily printed as a polymeric mockup.

Cell analysis and selection of the best topology

The nTopology software was exploited to investigate and compare several periodic lattice structures: the most suitable categories were the Strut-based one and the one based on Triply Periodic Minimal Surfaces (Fig. 1). The former consists of a series of tiny rods that are connected along different orientations. The latter are continuous structures generated from trigonometric equations [1].

In order to find the best candidate for our purpose, primarily, the specific area, i.e. the ratio of heat transfer surface to heat exchanger volume, was considered for a comparison. In fact, this quantity is proportional to the exchanged thermal power [2]. Combining the geometry characteristics, it was possible to classify the cells as follow (best first): SpliP, Diamond, Strut base, Gyroid and Schwartz. Since enhanced heat transfer and low-pressure drop are antagonist requirements [2], pressure drop, together with printability and cell topology, were included as further quality indexes to identify the best compromise for the HX core.

The conclusion of this extended comparison brought the cubic gyroid as the most suitable elementary cell for the heat exchanger core.

HX design development

The original gyroid cell geometry generated via nTopology, was cleaned with SpaceClaim and Siemens NX. This led to the elementary CAD object, that, replicated, was used for generating the heat exchanger core. The first HX design was meshed with Ansys meshing exploiting polyhedral cells. This approach contained the overall number of cells to 6.36 million with a maximum skewness of 0.8 [3]. Cell inflation nearby the walls was introduced to properly model the boundary layer (Fig. 2). The initial layout gradually evolved into the final one, depicted in Fig. 3, where the hot and cold fluid domains are highlighted in red and blue, respectively. To limit the overall pressure loss, connections which smoothly guide the flow form the external ducts to the core were implemented. Moreover, on the cold side, to enhance the heat transfer, some baffles were introduced to force the flow into a wavy path. The same solution was not implemented on the hot side to contain its pressure drop to levels similar to the original shell and tube heat exchanger (i.e., about 8 kPa at 7 l/min on tube side), assuring the full compatibility with the service unit pumping performance.

The heat transfer area of 20'000 mm^2 of the shell and tube was maintained while the HX volume was half of the original one. The final layout combines the potentialities of additive manufacturing, in terms of flexible and innovative solutions, and the more traditional elements, such as baffles and distributors/collector, into a custom-design tailored to the specific system constrains. The final layout is thought to be manufactured by using steel AISI 316L.

CFD numerical results and conclusions

Even though the k-ω SST turbulence model was initially preferred because of its better performance in conditions such as fluid flow separation, the k-ε Realizable with Enhanced Wall Treatment was used in the end due to the better convergence reached in the extensive numerical tests campaign.

The simulations confirmed the adequate mesh resolution (e.g., wall Y+ < 5). The pressure drop across the heat exchanger channels were about 9 kPa and 21 kPa on the hot and cold sides, respectively. As specified above, the former was found compliant with the HX service unit requirement.

A hybrid performance comparison was done between the new HX simulations and the shell and tube HX experiments. At the same operating conditions, the new HX (simulated) effectiveness was 40% higher than that shown (experimentally) by the shell and tube one [4]. Figure 4 depicts the temperature contours in several cross sections of the new HX. Figure 5 compares the dimensions of a real size polymeric mockup of the new HX (front view on the l.h.s. and top view mid-section on the r.h.s.) with the original Armfield shell and tube one.

References

[1] https://gen3d.com/news-and-articles/types-of-lattices-for-additive-manufacturing/

[2] https://www.stiral.com/microchannel/

[3] M. Sosnowski, J. Krzywanski and R. Gnatowska "Polyhedral meshing as an innovative approach to computational domain discretization of a cyclone in a fluidized bed CLC unit" DOI: 10.1051/e3sconf/20171401027

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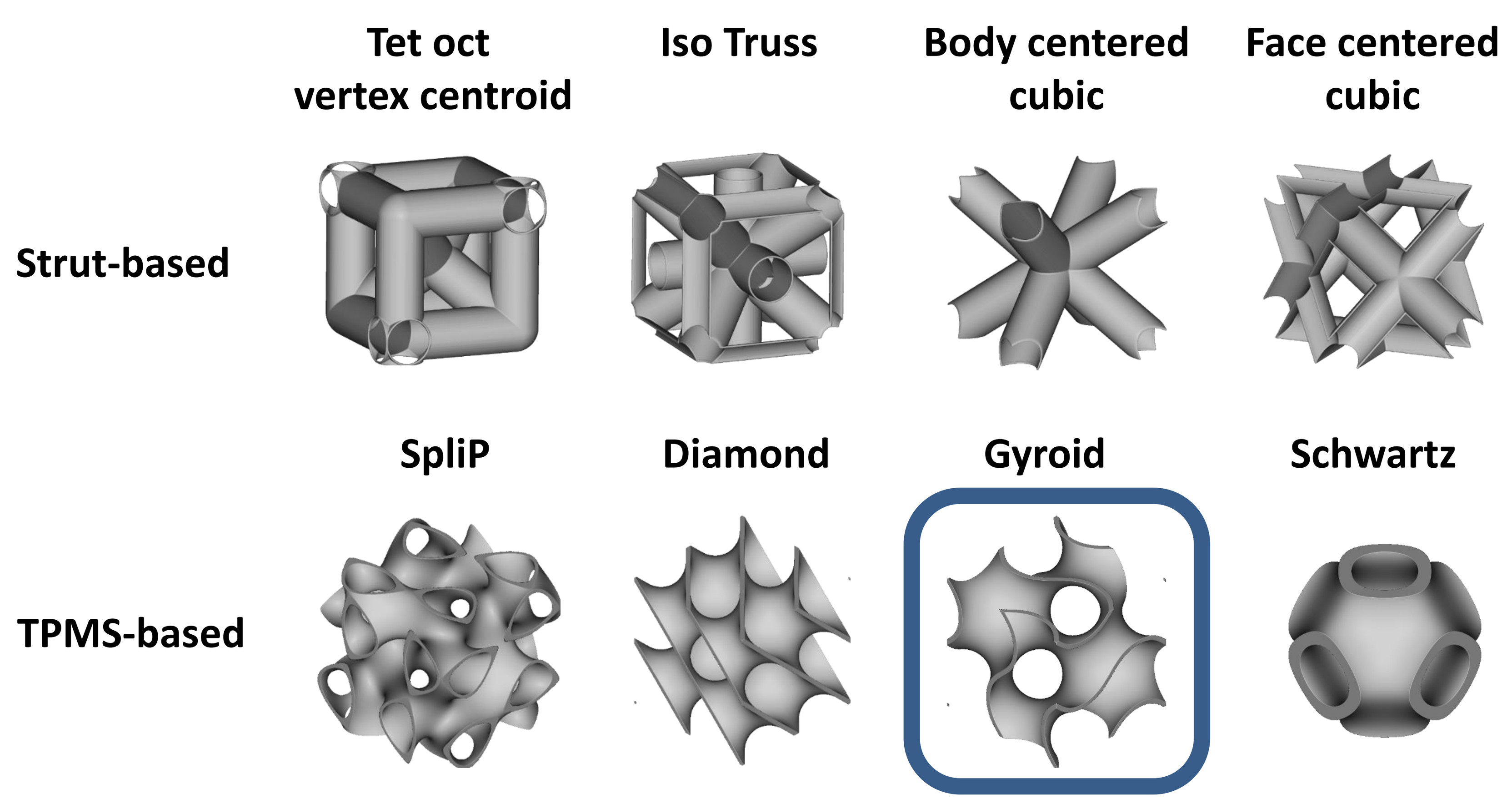

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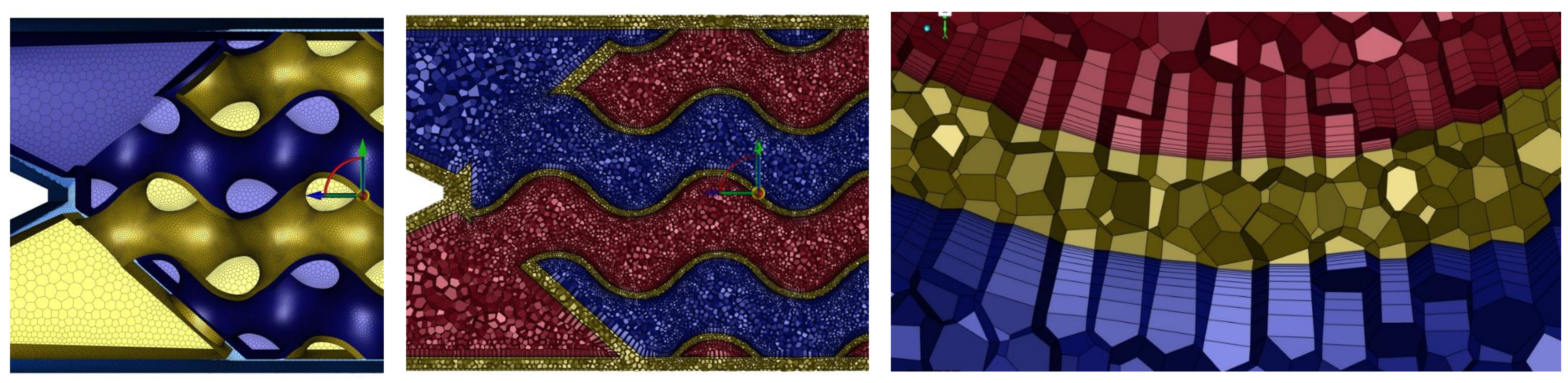

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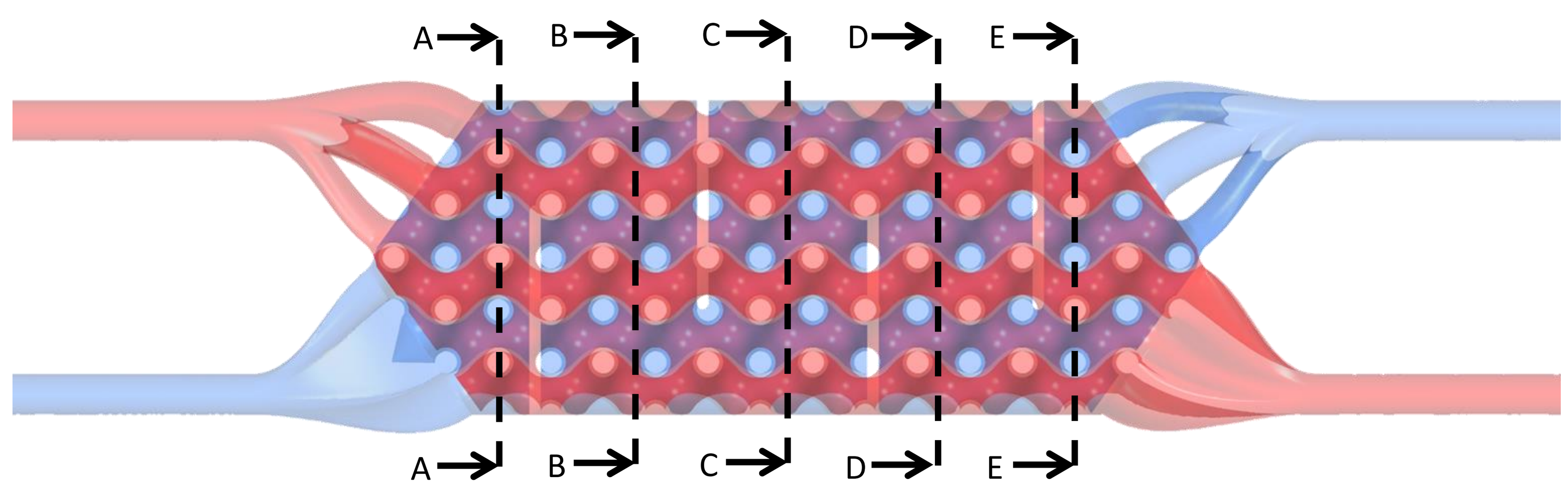

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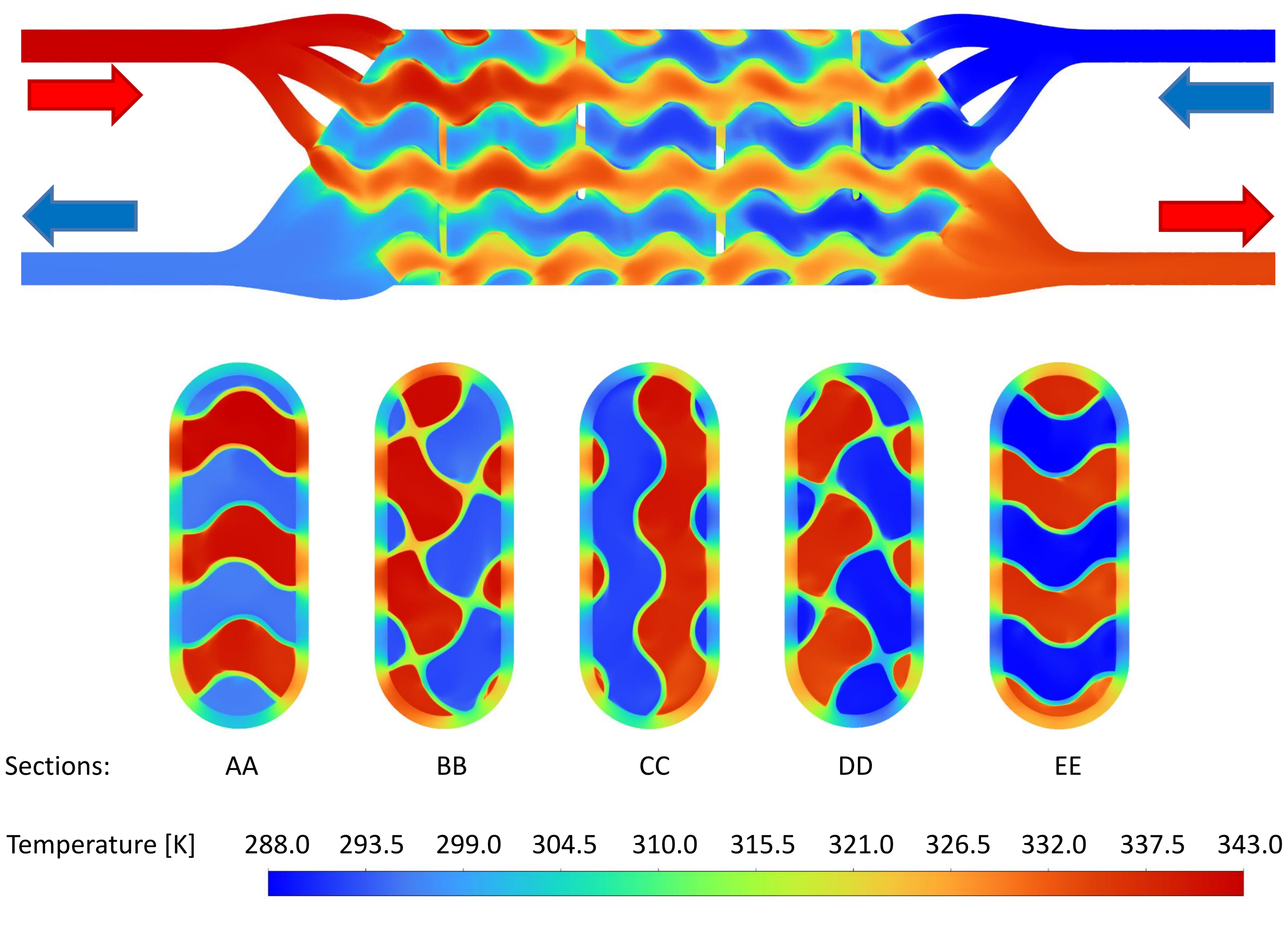

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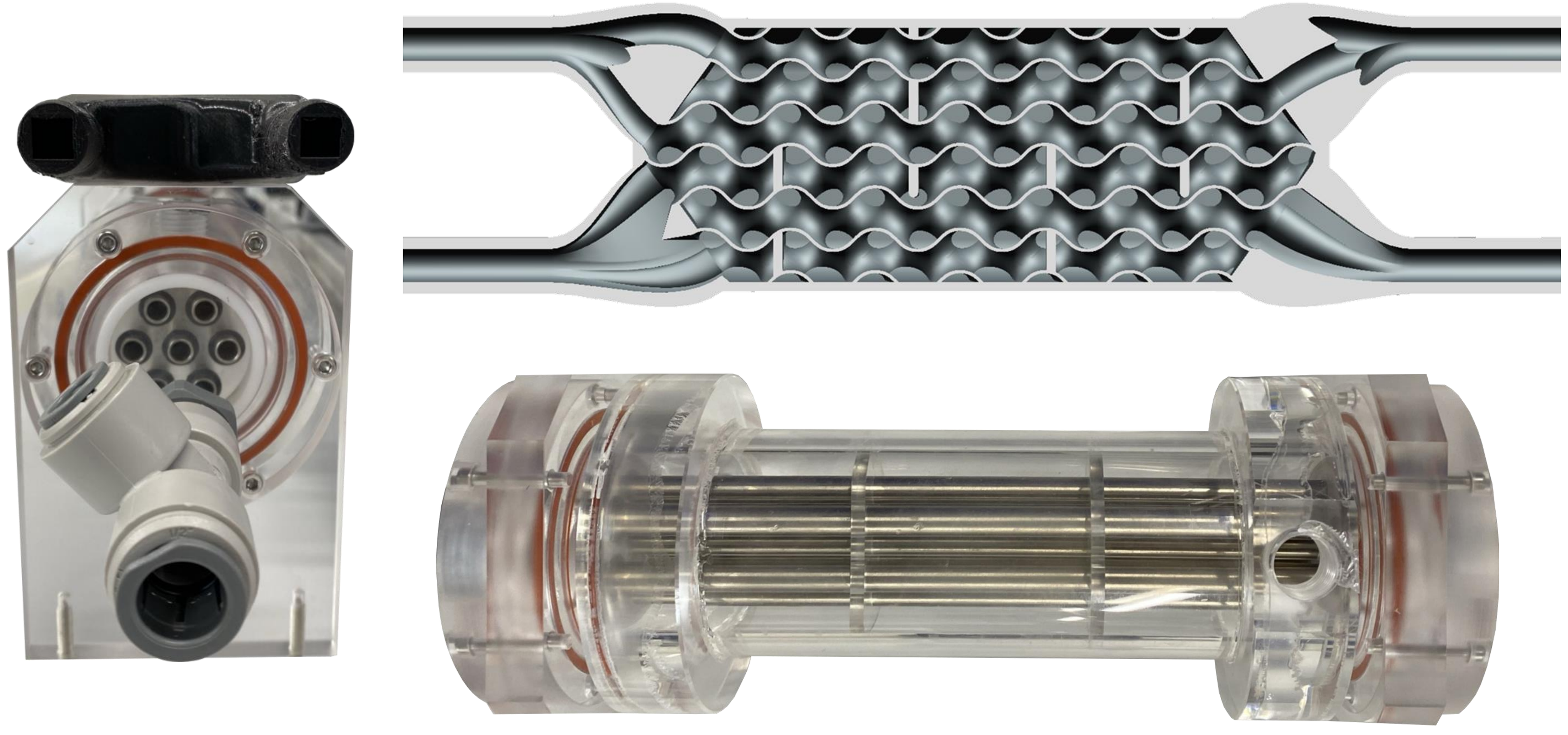

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