Experimental Characterization of High-Surface Area Thermal Energy Storage

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Project Objective

To design and test a Triply Periodic Minimal Surface (TPMS) heat exchanger for phase change thermal energy storage (TES).

Background

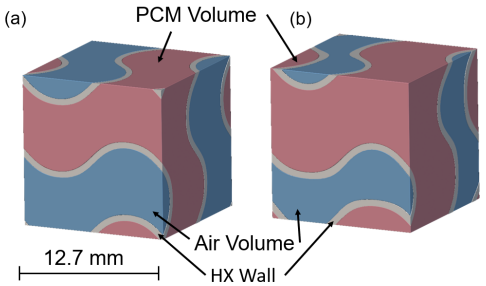
TES has applications in numerous areas from space conditioning to electronics thermal management [1,2]. A phase change material (PCM) is a common TES approach, typically selected for optimal melt temperature and large latent heats [3]. PCM-to-Air heat exchangers (PAHX) allow for direct heat transfer with conditioned spaces, increasing TES flexibility [4].

Low-temperature PCMs often have low thermal conductivity, making the design of the heat exchanger critical to achieving required heat transfer rates in many applications [5]. This study explores the use of TPMS surfaces to enhance the performance of PAHXs in a novel prototype.

Methodology

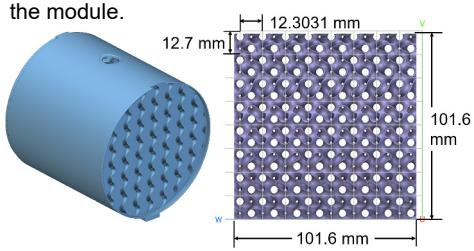
Typically, a TPMS equation such as the one below, provides a surface that evenly bisects the specified volume, shown in (a). For a TES device to have a high energy density, the PCM volume should be greater than the volume of the working fluid. To achieve this, a wall offset is used, shown in (b).

$$[sin(\frac{2\pi x}{X})cos(\frac{2\pi y}{Y}) + sin(\frac{2\pi y}{Y})cos(\frac{2\pi z}{Z}) + sin(\frac{2\pi z}{Z})cos(\frac{2\pi x}{X})] = 0$$

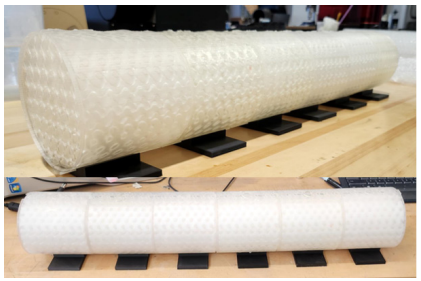


Methodology cont.

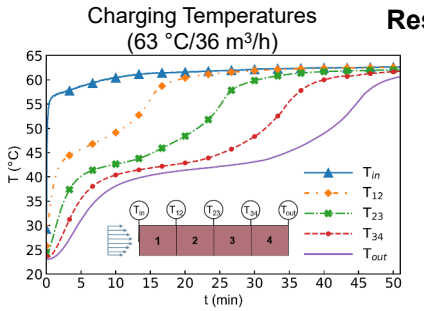
The TPMS surface created is used to fill the inside of a "module", designed to interface with a 101.6 mm diameter duct. Baffles are added around the outer wall and the front/back faces to contain the PCM volume. Lastly, a fill hole is added to the top, that is sealed after the PCM is added to the module.

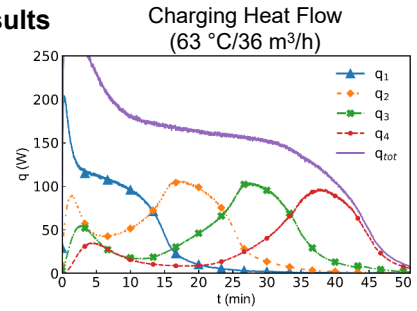


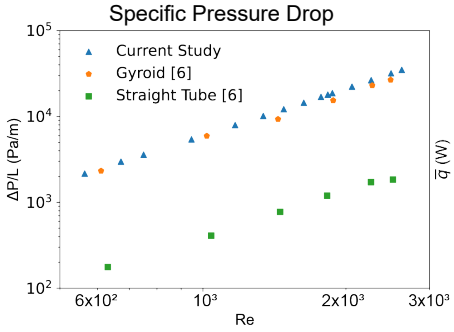
The modules are manufactured using a Formlabs 3B SLA printer using Formlabs Clear resin. A commercial organic phase change material, PCM 43 from Microtek Laboratories was used to fill the modules.

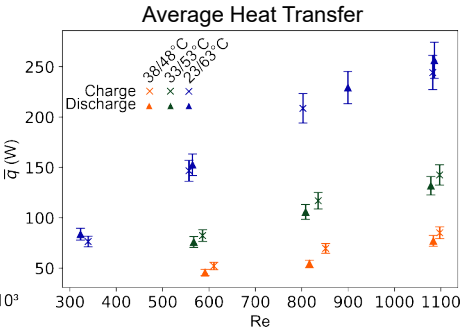


Results









Conclusions

This study showed a viable design approach to create TPMS based heat exchangers for TES systems that achieved high average heat transfer rates with large temperature differences over the duration of the charge/discharge. The inlet temperature delta and flow rate are the primary drivers of average heat flow, although flow rates influence appears to decrease at higher magnitudes. There is a high pressure drop penalty for the increased heat transfer rate, but the advantage of a constant outlet temperature is useful in many temperature sensitive use cases such as electronics cooling.

Recommendations

Potential next steps should include: reduced scale evaluation of additional unit sizes and TPMS surfaces to better understand all potential design variables and for comparison against traditional geometries. Additionally, validation of numerical tools could allow for modeling performance in a variety of applications and exploration of additional variables such as alternative PCMs.

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