Transient Thermal Energy Storage Device

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Abstract

Many high power electronic components operate on duty cycles and require cooling systems to handle heat generation. Traditional methods are to size a cooling system for the highest anticipated heat load, however large ratios between power modes render this design methodology inefficient. Temporarily storing the heat released during high power modes and releasing it during low power modes allows sizing of a cooling system closer to the average heat load generated. Our thermal energy storage device uses a phase change material with an efficient heat transfer design to store and release thermal energy in response to a cyclic heat load.

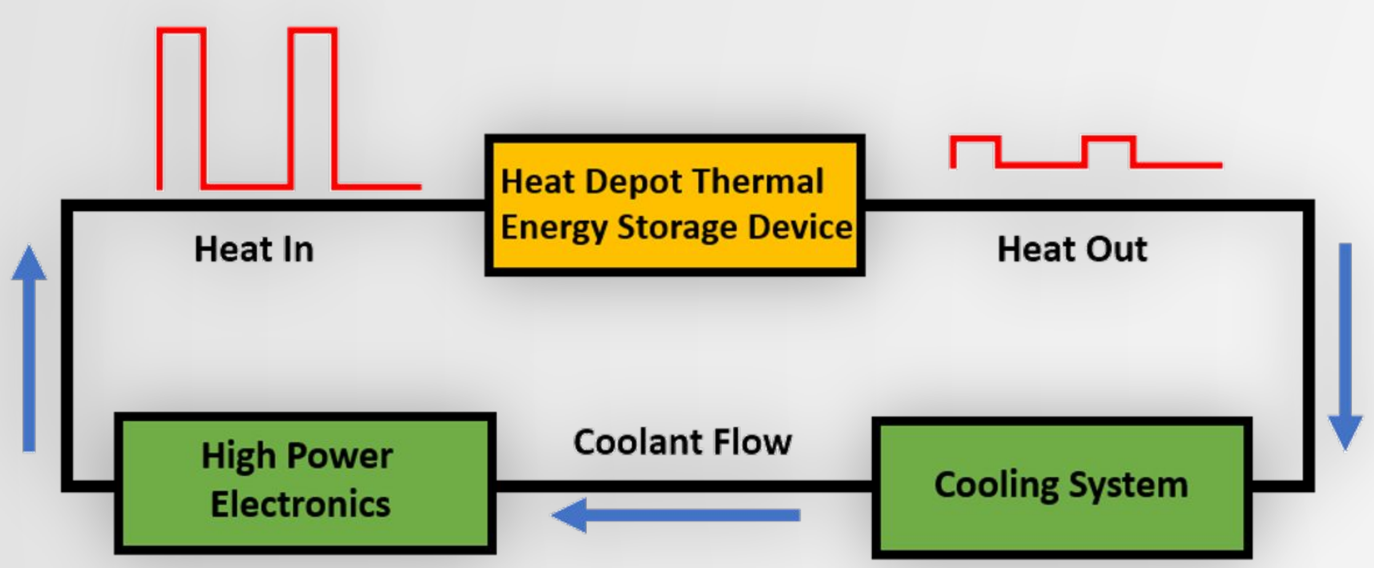

Figure 1: Cyclic-Heat-Load Liquid Cooling System Block Diagram

Key Components

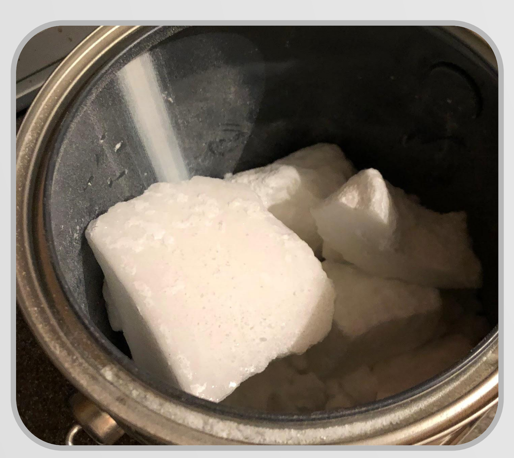

Figure 2: Pure-temp-37

Phase Change Material (PCM):
PureTemp-37 was selected due to its solid to liquid transition between the operating temperature range, high thermal energy storage capacity, and small volume expansion.

Finned Tubing:
In order to most effectively transfer heat between the coolant and the PCM, radial fins were used. Fin spacing was optimized using numerical optimization.

Figure 3: Aluminum finned pipe

Prototype

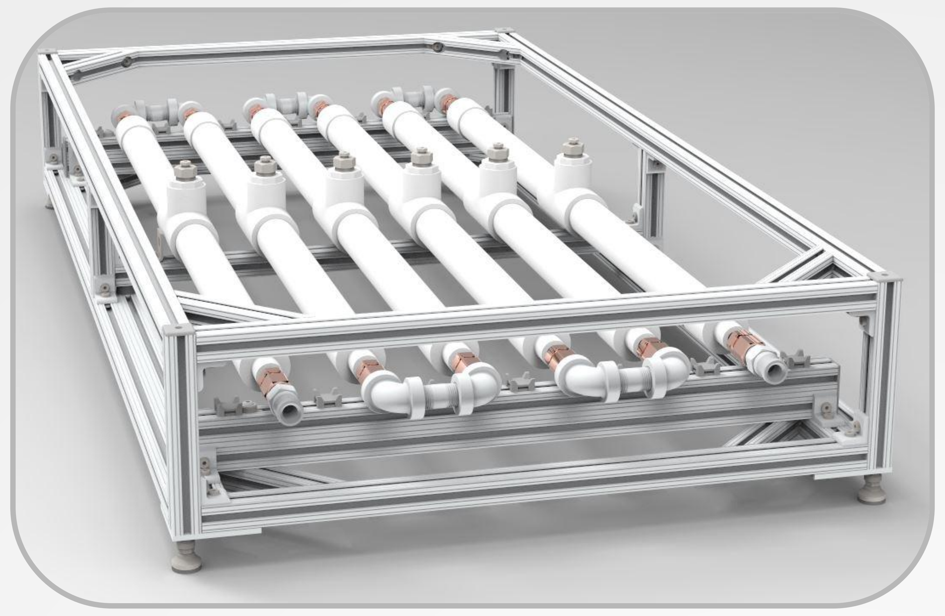

Figure 4: Rendered Image of Final Prototype

Final design includes 6 heat storage devices, as shown in Figure 5, connected in series. This modular design allows for various customer heat loads to be regulated efficiently.

1. Aluminum finned pipe
2. Turbulator
3. PVC outer shell
4. Relief valve

(PCM is filled between item 1 and 3)

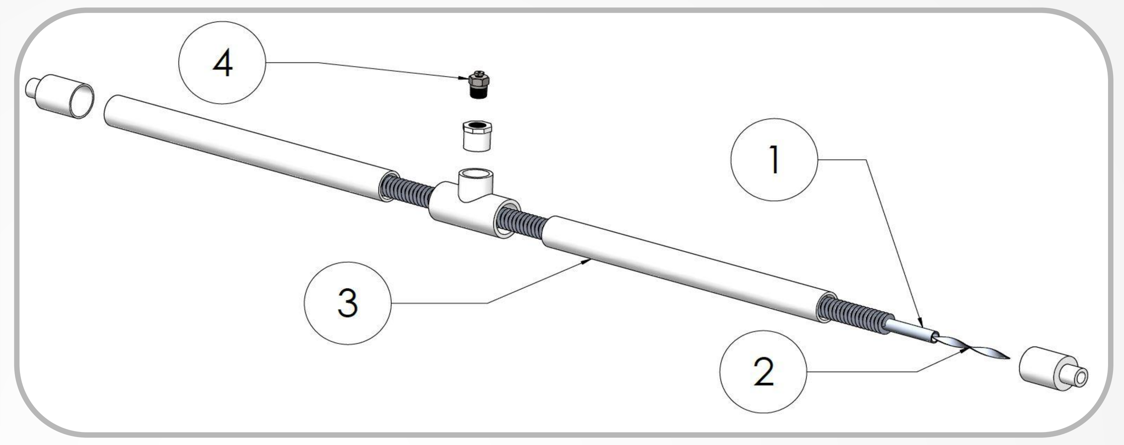

Figure 5: Exploded View of Heat Storage Device

PVC tubing is used to house the aluminum finned pipe and phase change material. A pressure relief valve is installed to allow thermal expansion. Aluminum and PVC were chosen for their density and heat characteristics as conductors and insulators, respectively.

Analysis

Type of Thermal Resistance	Calculated Value
Aluminum Tube Conduction	0.000178 Km/W
PCM Conduction	0.193 Km/W
Laminar Flow Convection	0.0433 Km/W
Turbulent Flow Convection	0.0122 Km/W

Table 1 : Thermal Resistance Comparison

Thermal resistance analysis showed the conduction resistance to the PCM is the limiting factor for heat transfer which led to the use of finned tubing. Turbulent flow is also shown to decrease convection resistance by a factor of 4. Turbulators were used to ensure turbulent flow conditions.

Numerical Optimization

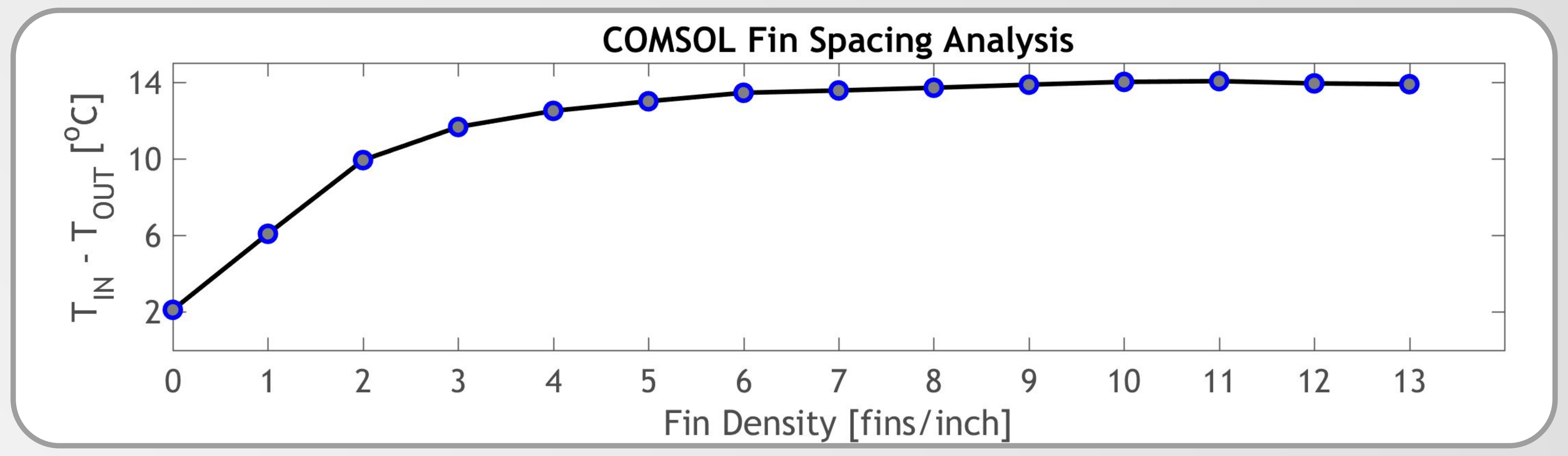

Figure 6: COMSOL Analysis of Optimum Fin Spacing

COMSOL simulation suggests that fin performance is asymptotic. A fin density greater than 10 fins per inch shows no reasonable performance gain.

Test Results

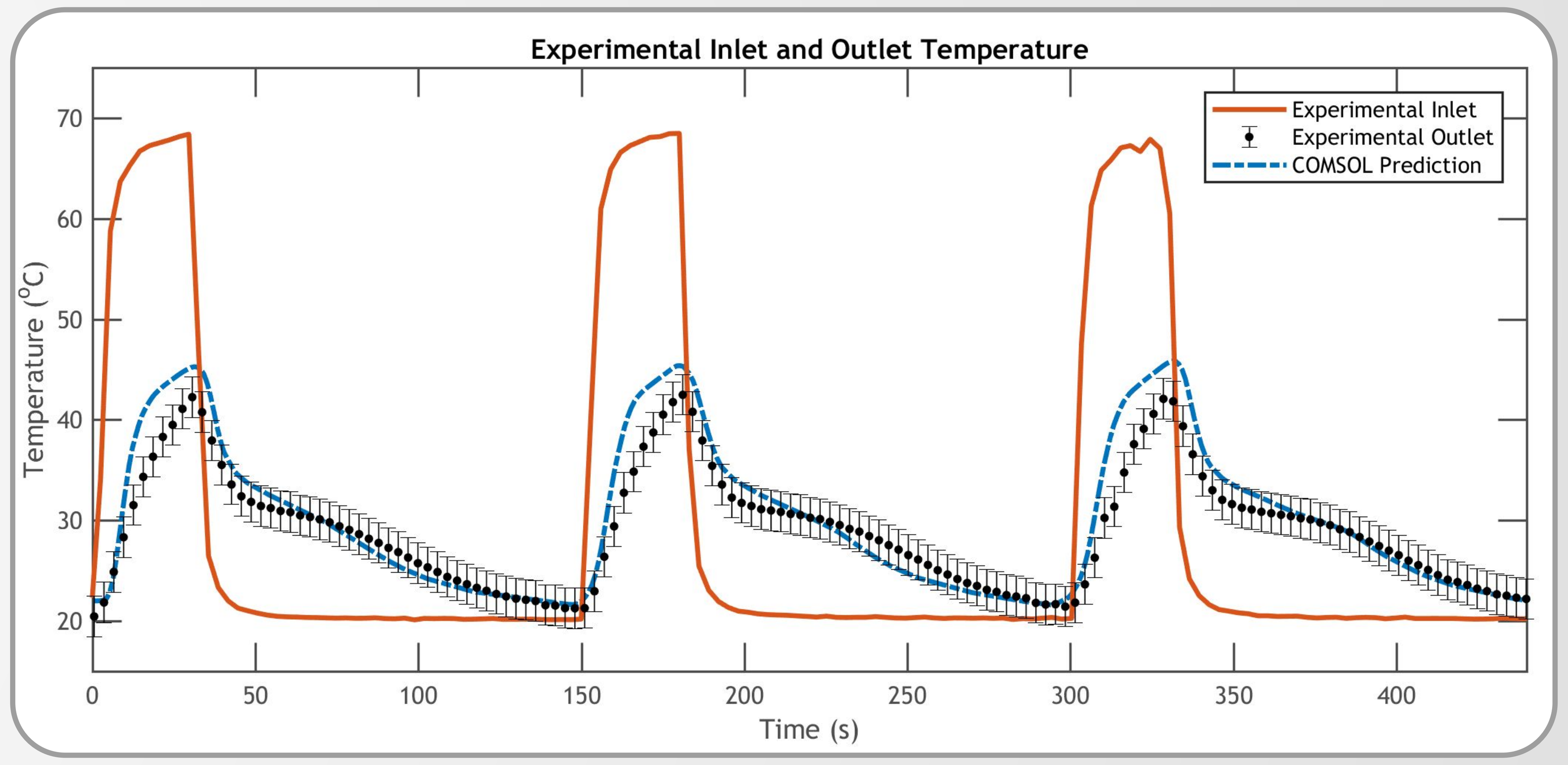

Figure 7: Experimental Inlet and Outlet Temperature

Cycle	Energy Absorbed	Energy Released	Residual Energy
1	362.90 kJ	307.76 kJ	55.137 kJ
2	364.08 kJ	328.73 kJ	35.353 kJ
3	354.10 kJ	333.96 kJ	20.135 kJ

Table 2 : Energy Calculations

The figure above shows the measured inlet and outlet temperatures with the associated uncertainty for the experiment. Also shown is the numerical simulation prediction which correlates well with the experimental results. Test results ultimately show a significant storage of heat that reduces the max temperature of 68℃ to 42℃ at a flow rate of 1.5 GPM.

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