Analysis of Heat Transfer in a Complex Three Dimensional Structure Fabricated By Additive Manufacturing

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Abstract

Introduction: The goal of this study was to create a three dimensionally designed biomedical device with multiple functionalities. The device would be fabricated through additive manufacturing; specifically electron beam melting (EBM). Unlike traditional manufacturing where a machine chips away at a piece of material to form the design, additive manufacturing builds onto the surface to create the intended result. In the case of EBM, consecutive coatings of sand-like metal are layered upon each other, then melted together to form the part[1]. The technique is advantageous in that its process allows for the fabrication of titanium-based products; a metal that is commonly utilized in the medical implant market[2]. This extensive usage is due to its biocompatibility that comes from the surface oxide layer which inhibits interaction between the metal and the body[3].

For the design of biomedical devices, EBM has a feature size constraint of 1 mm and is only capable of manufacturing titanium alloys[4]. The sizing limitation will be acceptable for this design; however, further functional components need to be added separately. In this simulation, we use silicon IC chips as the attached functional elements then use the model to analyze the simulated heat transfer of a complex three dimensional device.

COMSOL Multiphysics® Use: The design was simulated in COMSOL Multiphysics® software to test its functionality in a way similar to that of a heat sink channel[5] using a model imported from SolidWorks with three separate domains. The device has a helix shaped titanium body with channels running through the center of each vessel (see figure 1). Attached to this structure are 16 silicon chip components that generate heat, each having the same power consumption. Once simulation testing began, the channels had water running through them to produce cooling. The water had a starting temperature of 283 K while the power dissipated from the silicon chips as well as normal inflow velocity of the water were modified to see how they affected the output temperatures.

Results: The results of these tests can be seen in figures 1- 4 attached.

The volume temperature in figure 1 shows temperature highest at the bottommost located heat sources (silicon chips). The water in the channel as well as the titanium show an increase in

temperature moving down the structure; a relationship that can also been seen on the surface in figure 2. In figure 3, there is a decreasing exponential relationship between output temperature and velocity and in figure 4, a linear relationship.

Conclusion: It was determined from this simulation that as the flow rate increased, the output temperature was lower. This is reasonable because with increasing flow rate, the water is spending less time in the channel and therefore has less time to acclimate to the adjacent heat from the system. The output temperature also increased with increasing power from the system. As the power intensified, more heat was produced so this result is also rational. From these observations, we conclude that the devise design and characteristics can be optimized through this COMSOL analysis.

Reference

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5. Weilin Qu and Issam Mudawar. "Analysis of three-dimensional heat transfer in micro-channel heat sinks." International Journal of heat and mass transfer 45. 2002: 3973-3985.

Figures used in the abstract

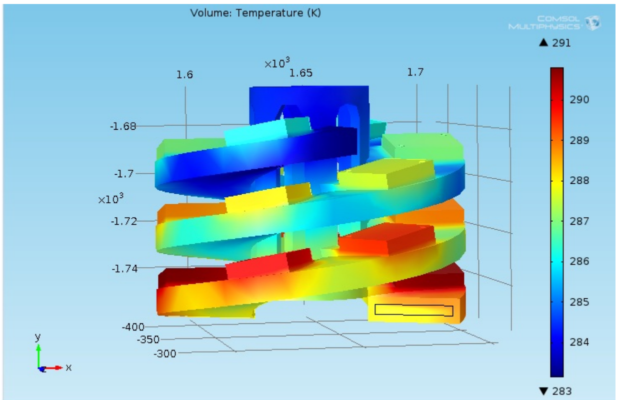

Figure 1: Volume Temperature of Heat Sink Channel (.005 m/s normal inflow velocity; 25W power).

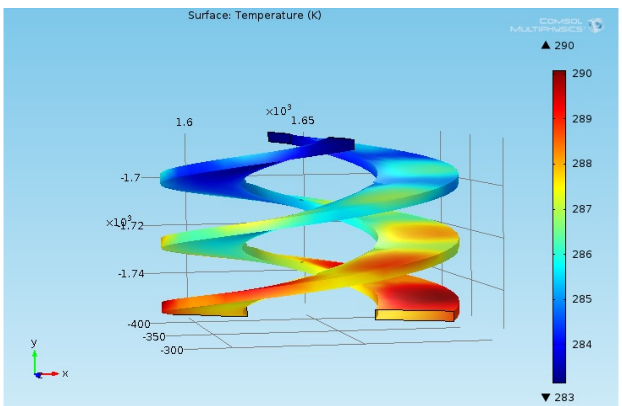

Figure 2: Surface Temperature of Heat Sink Channel (.005 m/s normal inflow velocity; 25W power).

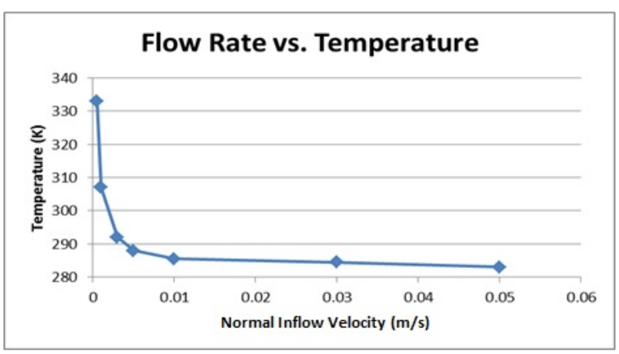

Figure 3: Normal Inflow Velocity vs. Output Temperature (25W power).

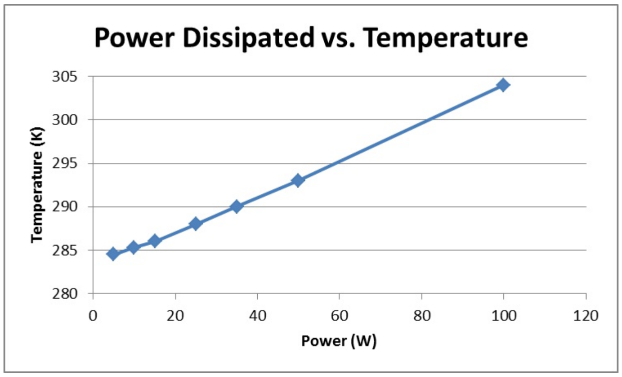

Figure 4: Total Power Dissipated vs. Output Temperature (.005 m/s normal inflow velocity).