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Numerical Investigation of Thermal-flow Characteristics of Heat Sinks with Lattice Structures and Pin Fins

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Extended Abstract

There is a growing demand for compact advanced thermal management systems to effectively dissipate heat generated by high-power technologies. Traditional cooling methods are often inadequate in meeting the increasingly severe thermal management requirements [1]. Therefore, novel approaches such as additive manufacturing have attracted considerable attention due to their potential to overcome the limitations of fabricating complex structures [2]. Additive manufacturing enables the creation of novel, compact structures with greater surface-to-volume ratios and geometries than standard pin/fin arrays. We propose special architected heat sinks suitable for additive manufacturing techniques, particularly triply periodic minimal surface (TPMS), and investigate their performance using the computational fluid dynamics (CFD) approach. This research presents a comprehensive numerical investigation into the thermal-flow characteristics of heat sinks featuring lattice structures and pin fins. The primary objective is to enhance the efficiency of thermal management systems crucial for various engineering applications, including electronic equipment. Specifically, our focus extends to high-temperature systems such as those in aerospace and aeronautics.

Triply periodic minimal surfaces (TPMS) have demonstrated superior mechanical performance, mass transfer, and thermal conductivity compared to traditional structures employed across various fields. Despite this, there has been limited research into using TPMS in microchannel heat sinks [3]. In this study, using COMSOL Multiphysics software, various heat sinks with different lattice structures and their integration via pin-fins are compared with conventional pin-fin heat sinks. This heat sink consists of a rectangular cooling channel with architected structures heated with constant heat flux. Different parameters, including Reynolds number, coolant type, geometric configurations of lattice structures, and pin-fin arrangements, are investigated to examine their effects on heat transfer enhancement, flow behavior, and pressure drop. The results revealed that TPMS characteristics such as porosity, wall thickness, and unit size notably affect the flow patterns and heat transfer behavior. Moreover, a comparative analysis between TPMS and conventional heat sinks highlighted that most TPMS configurations exhibit superior thermal efficiency compared to traditional methods while imposing a moderate increase in pressure drop. TPMS structures disrupt the flow patterns, promoting turbulence and enhancing convective heat transfer rates. Furthermore, optimizing geometric parameters like lattice cell size, pin-fin height, and density maximized thermal performance while minimizing pressure drop. Overall, the study demonstrated the capability of additive manufacturing in building complex geometries, which can improve thermal management systems across various industries.

References

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