Communication

# Design Effect of a Mini Channels Heat Sink Using Additive Manufacturing

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**ABSTRACT:** The present work aims to examine the influence of designing mini channel heat sinks using Stereolithography (SLA) 3D printing. Stereolithography (SLA) is a common additive manufacturing technique. The internal mini channels of the heat sink are made of aluminium materials and the outer cover is made of commercial polymer. Three models of the mini channel heat sinks are considered. A constant heat flow is applied to the bottom wall of the heat sink, and water is used as a coolant. The flow and heat transfer were studied for different cooling speeds. The physical properties of the fluid provided good thermal performance for the heat sink, especially at increased flow rates. The acrylonitrile butadiene styrene (ABS) copolymer resin has shown its good insulator for the heat sink and has improved the performance of the heat sink. This study demonstrates that the ABS copolymer resin enhances the cooling of electronic components.

**Keywords:** Commercial acrylonitrile butadiene styrene resin (ABS); Mini-channel heat sink; Additive manufacturing (AM)



## 1. Introduction

The increasing need for effective heat management and dissipation solutions, particularly in the electronics field, has driven the development of innovative heat sink designs. Traditionally, metals such as aluminum and copper have been used for heat sinks due to their excellent thermal conductivity. However, the use of polymers in heat sink design has emerged as a promising alternative, offering unique properties and distinct advantages, especially for low-power electronic devices that require less energy dissipation [1].

Polymers are widely recognized for being lightweight, cost-effective, and easy to manufacture. When integrated into complex heat sink designs, they can offer alternative solutions to traditional metal-based heat sinks, especially in lightweight devices or applications requiring electrical insulation. Recent advancements in polymer science have led to the development of composite polymers with enhanced thermal conductivity, making them a viable option for heat dissipation in a range of applications, including consumer electronics, LED systems, and automotive components [1].

The research on improving heat sink performance and cooling efficiency has been a focus of several studies, each addressing different aspects of heat dissipation and improving the design and material optimization.

Guzej et al. [2] showed that altering the fluid flow inside the cavity could significantly enhance the overall cooling efficiency of heat sinks made from polymers. They tested two geometrically identical heat sinks, made from commercial ABS resin, differing only in the position of the fan gate. Their findings revealed differing temperatures at the heat source between the two heat sinks under identical conditions.

Yijun et al. [3] tackled the issue of excessive heat in electronic devices, often due to insufficient cooling. Their study focused on the design and structural optimization of heat sinks to improve the heat dissipation capability of electronic devices, thereby increasing their reliability, longevity, and overall performance.

In a related field, Gulia and Sur [4] explored recent advancements in microchannel heat sinks and microchannel heat exchangers, discussing the concept of microchannel cooling. They provided an extensive review of fabrication methods, experimental investigations, and numerical analyses, shedding light on the innovations in heat sink technologies.

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Huttunen et al. [5] conducted research on optimizing heat sink topology using the flexibility of Fused Deposition Modeling (FDM), which allows for the creation of complex geometries. They used a commercial polyamide-based composite for their study. However, they noted that there has been limited exploration of 3D FDM printed heat sinks with good thermal conductivity properties.

A separate study [1] highlighted the benefits of using polymers instead of metals in heat transfer applications, particularly in terms of reduced weight and cost. Despite the low thermal conductivity of polymers, they are already utilized in heat exchangers. The study proposed solutions to enhance polymer conductivity by incorporating highly conductive reinforcements and creating thinner walls, which reduce the overall thermal resistance of polymer-based heat sinks.

Bopanna et al. [6] focused on optimizing the design of Pin-Fin structures in heat sinks to improve heat dissipation. Using the Taguchi optimization method, they considered variables such as base plate thickness, fin height, width, and spacing. Their simulations in a steady-state environment revealed that heat sink models with mid-range thermal efficiency exhibited consistent performance, outperforming other models with less reliable characteristics.

The review by Tanusree Bera [7] discussed the significance of polymeric materials in biomedical 3D printing and emphasized the need for further innovations in biomaterials to unlock the full potential of additive manufacturing in the biomedical field.

Danilov et al. [8] provided an experimental study on composite materials, detailing their physical and physico-chemical properties, including thermal stability, dielectric constant, and thermal conductivity. The study demonstrated that manufacturing techniques involving high processing pressures result in materials with enhanced thermal conductivity and excellent dielectric properties, key for developing efficient heat sinks.

The study by Guzej et al. [9] demonstrated that polymer-based heat sinks filled with highly conductive materials, such as graphite flakes, could offer effective alternatives to traditional metals like aluminum and copper alloys for passive cooling. The study also showed that adjusting the melt flow within the mold cavity could improve the overall cooling efficiency of polymer heat sinks.

Finally, a recent study carried out by Devarajan et al. [10] conducted a comparison between traditional aluminum straight-fin heat sinks and three types of polymer-based straight-fin heat sinks produced using 3D printing. The polymers tested include Acrylonitrile Butadiene Styrene (ABS), Poly Lactic Acid (PLA), and Polyethylene Terephthalate Glycol (PETG). The experimental results revealed that the polymer-based heat sinks are 13% to 30% less effective in heat dissipation than their aluminum counterparts. However, these polymer alternatives can still be viable options for low-power electronic devices that have lower heat dissipation requirements.

The current study aims to investigate the impact of thermal heatsink designs made from different materials, such as ABS copolymer resin and aluminum, on improving the cooling efficiency of electronic components. This is achieved by comparing the performance of heatsinks made from these two materials through an analysis of their designs and various shapes, and evaluating their effect on enhancing the cooling process.

The importance of this work also lies in highlighting new models for the purpose of improving the efficiency of devices and systems that rely on heat dissipation, such as computers, cars, high-heat-producing devices, and renewable energy systems. This is achieved by adding insulating materials aimed at enhancing thermal insulation effectiveness and increasing performance efficiency under different temperature conditions. Additionally, it contributes to the ability of heat dissipation systems to absorb and distribute heat more effectively.

This study, which focuses on thermal dissipators using polymer resin as an insulating cover, is a relatively new topic that has not been extensively addressed by researchers before. With the ongoing advancements in the fields of electronic devices and renewable energy, interest in this subject is expected to grow among researchers. This growing interest may lead to the incorporation of new manufacturing methods, such as the use of 3D printing technology. This technology allows for the precise and cost-effective production of thermal dissipators. Moreover, it enables the optimization of polymer heat sink designs to meet the specific needs of complex devices, improving their efficiency in heat management.

## 2. Geometrical System

The figure below (Figure 1) illustrates three different geometric shapes of the heat sink. The inner mini channel walls of the aluminum heat sink (Figure 2a), while the external walls of the heat sink are printed by ABS copolymer resin using SLA printing (Figure 2b). The length, width, and height of the aluminum heat sink are 14 mm, 14 mm, and 6 mm, respectively.

The dimensions of the external walls are: length = 29 mm, width = 20 mm, and height = 8 mm.

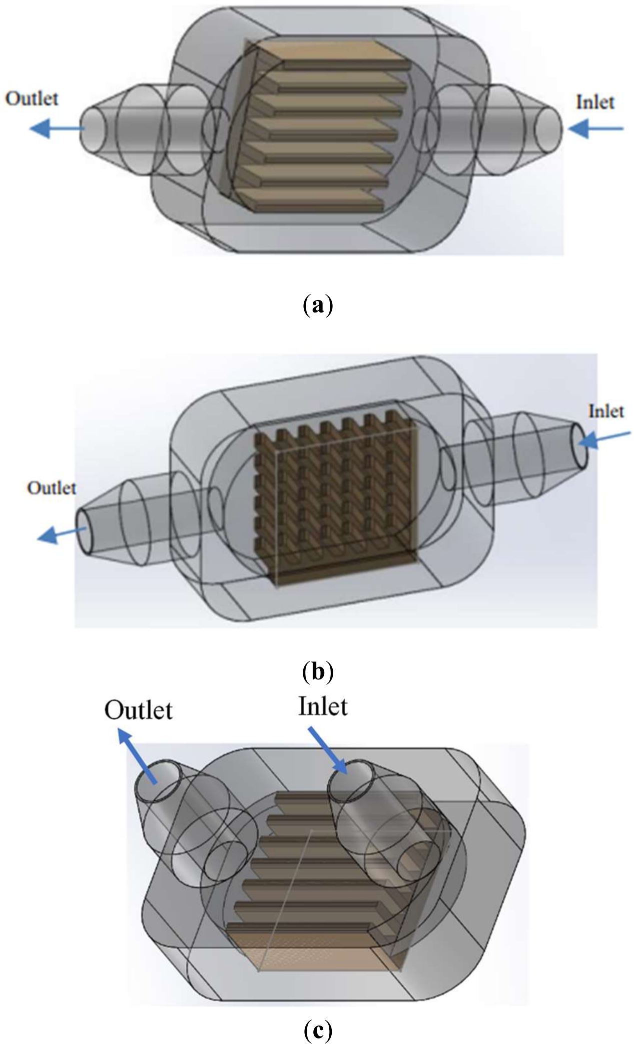



**Figure 1.** Shapes geometric studied. (**a**) case 01: Rectangular-channel heat sink featuring a horizontal inlet and outlet; (**b**) case 02: The mini pin fin heat sink with a horizontal inlet and outlet; (**c**) case 03: Rectangular-channel heat sink featuring a vertical inlet and outlet.

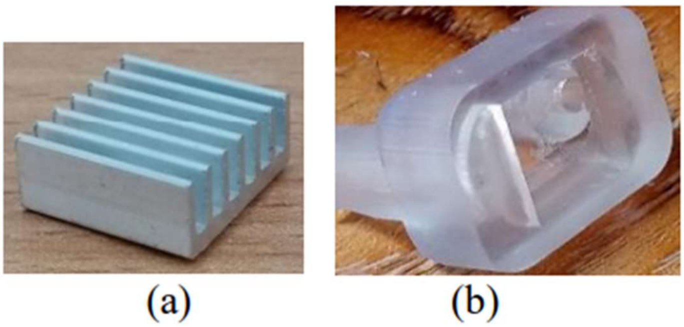



**Figure 2.** (**a**) Heat sink, (**b**) external walls.

According to the Table 1, we can notice water is excellent at storing thermal energy (due to its high specific heat capacity) but has lower thermal conductivity and density. ABS resin has the lowest thermal conductivity and specific heat, making it useful for insulation and lighter applications. Aluminum has a very high thermal conductivity, making it ideal for applications requiring heat transfer.

**Table 1.** The thermophysical characteristics of Aluminum, water and ABS copolymer resin.

| **Physical Properties** | **$\rho$ (kg m$^{-3}$)** | **$Cp$ (J kg$^{-1}$ K$^{-1}$)** | **$k$ (w m$^{-1}$ K$^{-1}$)** | **$\mu$ (kg m$^{-1}$ s$^{-1}$)** |
|---|---|---|---|---|
| Water | 998.2 | 4182 | 0.60 | 0.001003 |
| ABS resin | 1040 | 800 | 0.17 | -- |
| Aluminum | 2719 | 871 | 202.4 | -- |

## 3. Mathematical Formulation

In this study, the simplifying assumptions are mentioned below in order to approach the resolution of the equations governing the natural convection of a viscous fluid.

Continuity equation:

$$\nabla V = 0 \tag{1}$$

Momentum equation:

$$\rho(V\nabla V) = -\nabla P + \nabla(\mu \nabla V) \tag{2}$$

Energy equation:

$$\rho C_p\,(V\nabla T) = k\nabla^2 T \tag{3}$$

where $V$, $P$, $\rho$, $\mu$, $C_p$, $k$ and $T$ are the velocity, pressure, coolant density, dynamic viscosity of coolant, specific heat of the fluid, thermal conductivity and the temperature, respectively.

### *3.1. Simplification Hypotheses*

- Laminar flow
- The water is incompressible and Newtonian.
- The effect of the joule is negligible.
- Viscosity dissipation is negligible.
- It is assumed that the physical properties of water are constant.

### *3.2. The Boundary Conditions*

At the inlet of water are written as follows:

* Flow velocity ($V_Z$) and Temperature ($T$) at the inlet of the heat sink are constant.
* At the outlet, we can write: the guage pressure is zéro.
* No-slip boundary conditions are applied to all cases of mini channel wall.
* A constant heat flux is applied to the bottom wall (the heat source as an electronic component equal 98 watts of power).

## 4. Stability Testing of the Results

Figure 3 shows the effect of the number of elements in a mesh on the results of the average and maximum temperature of the heat source located below the heat sink. According to the results, when the number of elements increases from 300,537 to 1,092,272 elements, the results begin to converge in values (the values of the average temperature of the heat source range between 334.27 and 329.22 K). On the other hand, when the number of elements is small, *i.e.*, between 40,349 and 78,580 elements, the values of the heat source temperature diverge, *i.e.*, between 371.26 and 343.07 Kelvin.

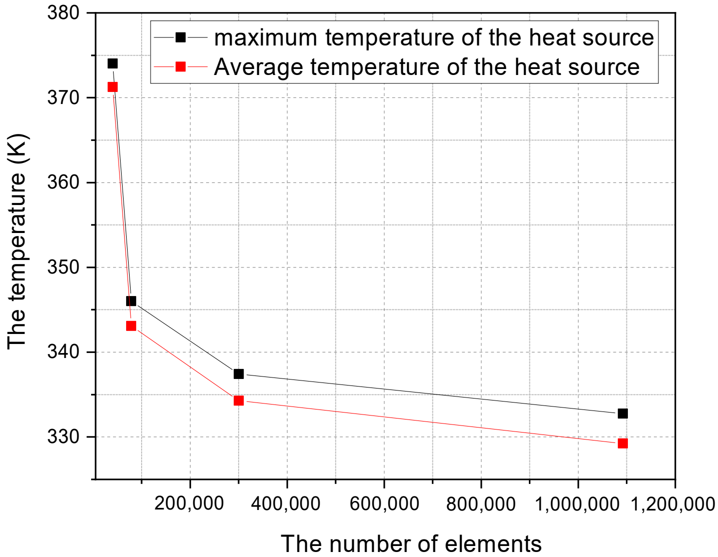


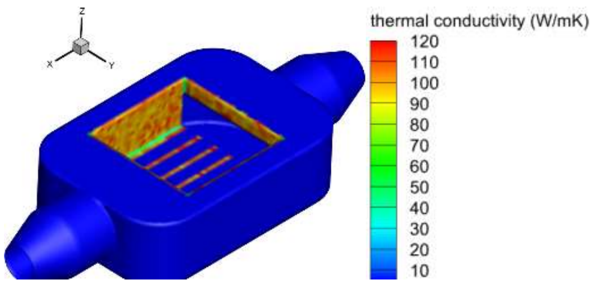

**Figure 3.** The effect of the elements number on the temperature results for case 01. (flow rate = 0.17 m/s).

## 5. Results and Discussion

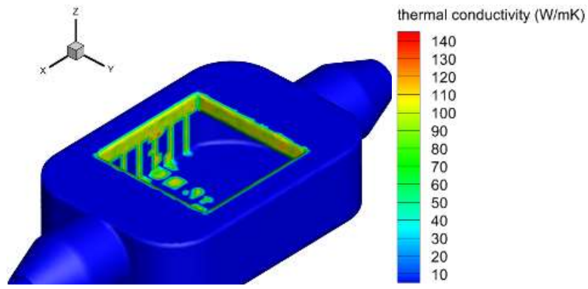
The results for the three models under consideration are in the form of isothermal patterns, streamlines of velocity, and the average temperature variation of the heat source.

Figure 4 illustrates the distribution of thermal conductivity for the heat-insulating outer walls made of ABS copolymer resin, which are connected to the hot walls of the mini channels of the heat sink made of aluminum. According to Figure 4, increasing the thickness of the outer walls reduces heat release to the outside. This is because when the insulating wall is thicker, the material's ability to resist heat flow becomes greater. Insulating materials reduce thermal conductivity, which is the process of heat transfer from a hot area to a cooler one. A thicker layer of insulation means that heat must pass through more layers of the insulating material, thus reducing the amount of heat that reaches the other side.

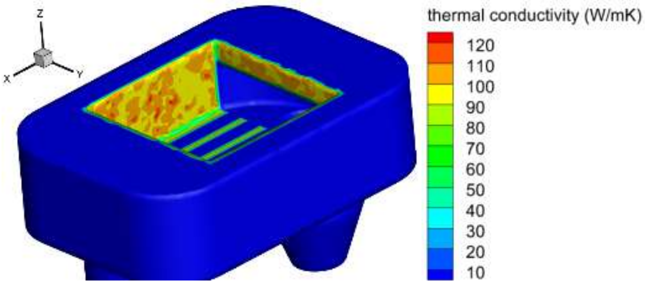
On the other hand, the temperature gradient within the cavity is observed to be due to the high temperature of the heat dissipation device, which contributed to transferring some heat to the sides of the polymer resin. This occurs because the insulating material can transfer some heat when exposed to high temperatures.




**Case 01**



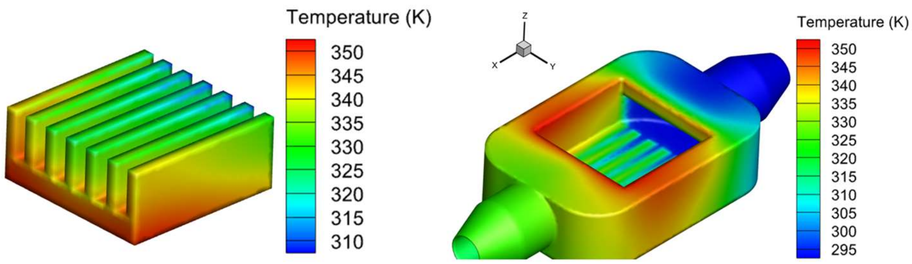

**Case 02**



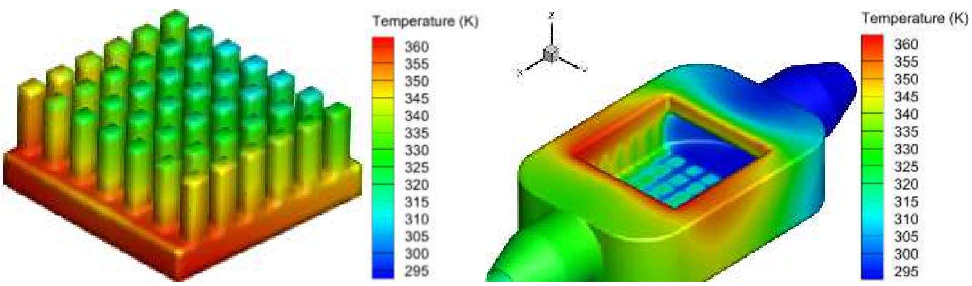

**Case 03**

**Figure 4.** The thermal conductivity distribution for external walls printed for three cases.

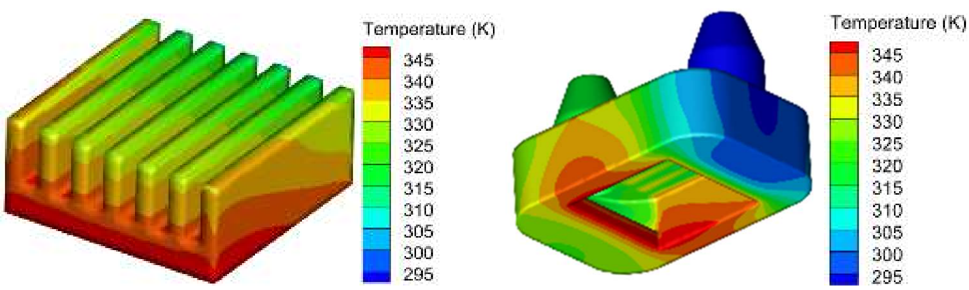
Figure 5 represents the temperature distribution for three configurations of heat sinks for the inlet speed of the water is equal to 0.07 m/s. The temperature distribution varies depending on the shape and design of the heat sink. While the maximum temperature on the heat source reaching 350 K, 360 K, and 345 K for the first, second, and third cases, respectively, the temperature for the inlet of the heat sink equals 295 Kelvin and the increase in the temperature at the outlet of the heat sink. In addition, the changing geometry of the aluminum heat sink has a significant effect on the temperature of the cooler. This is done by increasing the contact area between the heat dissipation surface and the cooling fluid; the heat exchange efficiency improves. This can be enhanced by modifying the design of the dissipation system to include fins or multiple blades, which increases the surface area exposed to the fluid. The more these fins are increased in number, the faster the heat absorption process from the fluid, leading to a more effective reduction in the system's temperature (temperature of the heat sink). On the other hand, cases 1 and 3 define the effect of the external wall design of the heat sink to reduce the temperature value of the heat source.




**Case 01**




**Case 02**




**Case 03**

**Figure 5.** The temperature distribution for three cases.

Figure 6 represents the distribution of temperatures for three cases at a level equal to 0.011 m from the bottom of the heat sink. It's observed the temperature of water (cooler) in the heat sink inlet is 295 K, and then the temperature of the water increases gradually from the center to the outlet due to the external walls intercepting the heat released to the external environment, and the water absorbs this heat from heat sink.

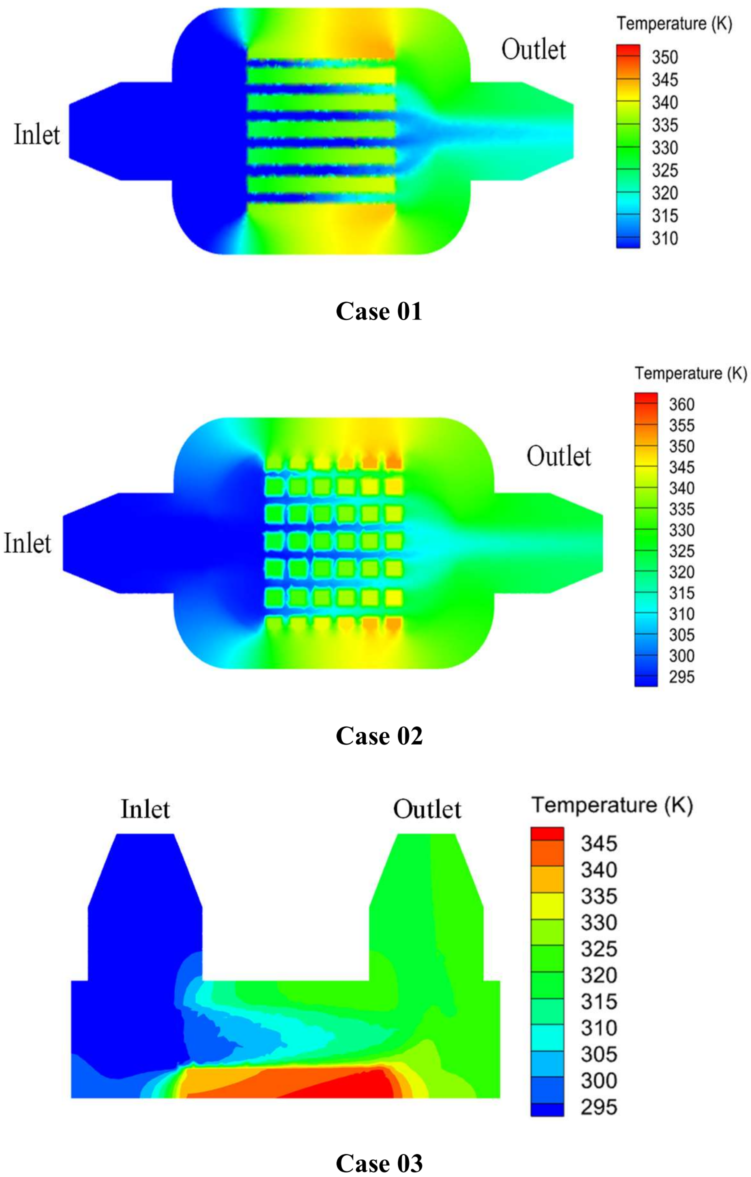



**Figure 6.** The temperature distribution for three cases at a level equal to 0.011 m from the bottom of the heat sink.

Figures 7 and 8 represent the variation in the maximum and average temperature values of the heat source as a function of the water inlet flow rate to the heat dissipater for three different cases. The results show that increasing the water flow rate leads to a decrease in the heat source temperature for all three cases. Specifically, when the flow velocity reaches 0.07 m/s, the average temperature of heat source values for the three cases are 347.56 K, 357.35 K, and 345.81 K, respectively. When the flow velocity is increased to 0.22 m/s, there is a noticeable decrease in the average temperature of the heat source, with values of 331.93 K, 337.94 K, and 330.11 K for the three cases, respectively.

Additionally, we observe that the average temperature of the heat source decreases further in the third case compared to the other two. For instance, at a flow velocity of 0.17 m/s, the temperature reaches 332.44 K in the third case, compared to 341.02 K in the second case and 334.27 K in the first case. This difference is due to the design shape of the third case, which enhances the flow movement within the mini channel of the heat sink. This improvement is achieved by changing the liquid inlet direction to the heat sink, which contributes to better heat transfer within the heat sink.

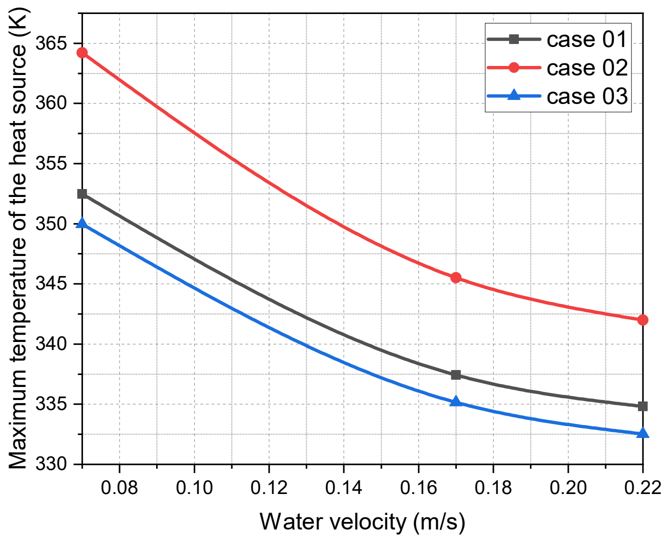



**Figure 7.** The variation of maximum temperature of the heat source *vs*. water velocity.

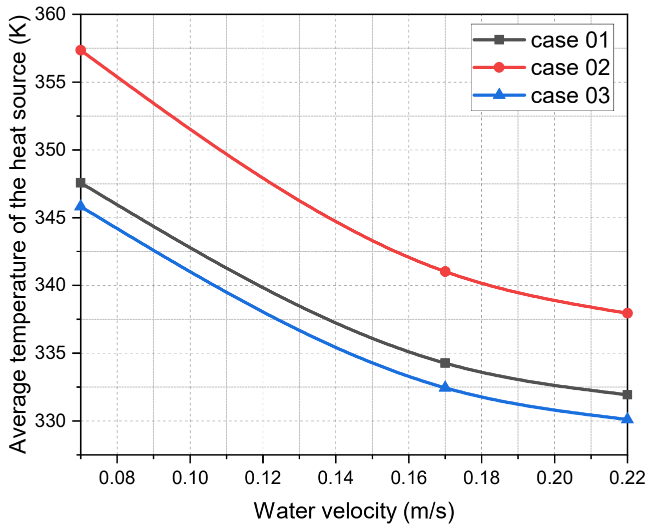



**Figure 8.** The variation of average temperature of the heat source *vs*. water velocity.

## 6. Conclusions

The objective of this study is to investigate the effect of the heat sink design made from aluminum and polymer resin using additive manufacturing. The study was conducted at different flow rates ranging from 0.07 to 0.22 m/s. The results obtained are summarized as follows:

- The insulation of the outer walls of the heat sink significantly contributes to improving the cooling process. This is because the insulating ABS copolymer resin helps reduce heat transfer from the external environment, allowing the dissipater to operate under more stable conditions. Additionally, it enhances the dissipater's ability to absorb and distribute heat more effectively, thereby improving thermal performance.
- Increasing the thickness of the insulating wall contributes to improving the effectiveness of the design.
- The design of the third case proved its effectiveness in reducing the heat source temperature.
- Increasing the flow rate (water) leads to a decrease in the heat source temperature.
- These results contribute to the development of using ABS copolymer resin materials in designing a complex heat sink using additive manufacturing technology.
- From a manufacturing perspective, technologies such as injection molding and 3D printing provide cost-effective and scalable solutions for producing polymeric heat sinks with complex designs.

Looking ahead, advancements in nanomaterials and hybrid polymers suggest that polymeric heat sinks will continue to evolve. The integration of these advanced materials could enhance heat dissipation properties.

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## Author Contributions

This research was conducted by the authors listed at the top of the article (K.C., A.B.), who carried out data processing and verified the research results to ensure their accuracy and reliability.

## Ethics Statement

The authors confirm that this work is original and has not been previously published. It has been developed independently.

## Informed Consent Statement

No informed consent statement.

## Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author.


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## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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