Simulation Study of Pin-Type Heatsinks on Convection Heat Transfer Characteristics in Electronic Devices

Noverto Zhorif Chaniago[a], Devia Gahana Cindi Alfian[a, *], Muhammad Syaukani[a], Eko Pujiyulianto[a], Fajar Perdana Nurullah[a], Dicky J. Silitonga[a]

[a]Department of Mechanical Engineering, Faculty of Industry Technology, Institut Teknologi Sumatera

Jl. Terusan Ryacudu, Way Huwi, Kec. Jati Agung, Kabupaten Lampung Selatan

*E-mail: devia.gahana@ms.itera.ac.id

Abstract

Electronic components are components that require an optimal design in order to provide good heat release performance. The heat sink component is a relevant solution to help cool an electronic component by flowing heat energy into the environment either naturally or forcibly with the help of a fan. The purpose of this study is to determine the effect of material type on heat sink temperature distribution, determine the phenomenon of velocity boundary layer and thermal boundary layer that occurs in each heat sink variation, determine the effect of design shape and pin arrangement on pressure drop, determine the best design according to the final results of the study. This research uses 6 variations of design shape, 2 variations of arrangement (inline and staggered), and 3 types of materials (Aluminum, Copper, and Iron). The method used in this research is a simulation method with three stages of process, namely, pre processing, processing, and post processing. The results showed that copper material is the best in conducting heat with a temperature drop of 98.5% from the base temperature. The inline arrangement obtained a lower pressure drop than the staggered arrangement and the best design was obtained by fillet square perforation with an inline arrangement.

Keyword: *heat sink, velocity boundary layer, thermal boundary layer, pressure drop, simulation*

Abstrak

Komponen elektronik merupakan suatu komponen yang memerlukan desain yang optimal agar dapat memberikan performa pelepasan panas yang baik. Komponen *heat sink* merupakan sebuah solusi yang relevan untuk membantu pendinginan pada sebuah komponen elektronik dengan mengalirkan energi panas ke lingkungan baik itu secara natural maupun secara paksa dengan bantuan kipas. Tujuan penelitian ini adalah mengetahui pengaruh jenis material terhadap distribusi temperatur *heat sink*, mengetahui fenomena *velocity boundary layer* dan *thermal boundary layer* yang terjadi pada setiap variasi *heat sink*, mengetahui pengaruh bentuk desain serta susunan *pin* terhadap *pressure drop*, mengetahui desain terbaik sesuai dengan hasil akhir penelitian. Penelitian ini menggunakan 6 variasi bentuk desain, 2 variasi susunan (*inline* dan *staggered*), dan 3 jenis material (Alumunium, Tembaga, dan Besi). Metode yang digunakan pada penelitian kali ini adalah metode simulasi dengan tiga tahap proses yaitu, *pre processing, processing,* dan *post processing.* Hasil penelitian menunjukkan bahwa material tembaga yang terbaik dalam menghantarkan panas dengan penurunan temperatur sebesar 98,5 % dari temperatur dasar. Susunan *inline* memperoleh *pressure drop* lebih rendah dari susunan *staggered* dan desain terbaik diperoleh oleh perforasi persegi *fillet* dengan susunan *inline.*

Kata kunci: *heat sink, velocity boundary layer, thermal boundary layer, pressure drop,* simulasi

1. Introduction

Various technological components that are developing today must produce heat in carrying out their work processes. The heat sink component is a relevant solution to help cool an electronic component by flowing heat energy into the environment either naturally or forcibly with the help of a fan. Heat sinks are used for reasons of low cost, light weight, and good heat release performance. In designing a heat sink there are several things that need to be considered such as the constituent materials, shape, and also the arrangement. Some of these things certainly affect the performance of the heat sink in conducting heat transfer. Based on previous research references conducted by Ambreen et al, 2019 by varying the shape of the heat sink such as square, circle, and triangle shapes. The circular shape obtained better heat transfer performance than the square and triangular shapes. The circular shape helps reduce the pressure drop that can inhibit the air flow in the heat sink [1]. Research conducted by Ghyadh et al, 2021 by conducting convection heat transfer tests on a circular heat sink by comparing shapes that do not have perforations and have perforations. The shape of the perforations helps the circulation of air flowing in the heat sink to be better, thereby increasing the cooling efficiency [2]. Research conducted by Mueller et al, 2020 by conducting one of the material variations on the heat sink with the aim of optimizing the design, obtained the lowest surface temperature by diamond material and followed by copper, aluminum, and iron materials. Diamond material does get good performance but, in terms of cost and functionality, aluminum, copper, and iron materials are more favored [3]. Based on these studies, the authors want to conduct research using numerical simulation and analysis methods by varying the shape of the circle, arrangement, type of material and adding variations in the shape of the perforation to see the phenomenon of heat transfer treatment that occurs. The objectives of this study are, knowing the effect of material type on heat sink temperature distribution, knowing the phenomenon of velocity boundary layer and thermal boundary layer that occurs in each heat sink variation, knowing the effect of design shape and pin arrangement on pressure drop, knowing the best design according to the final results of the study.

2. Materials and Methods

Some important data in this heat sink simulation test, such as the variations used, test models, and material properties, can be seen below:

2.1 Simulation Model and Geometry

The six heat sink designs used in this research are solid variations and variations with different perforation shapes as well as inline and staggered arrangement variations. The design can be seen in Figure 1 below:

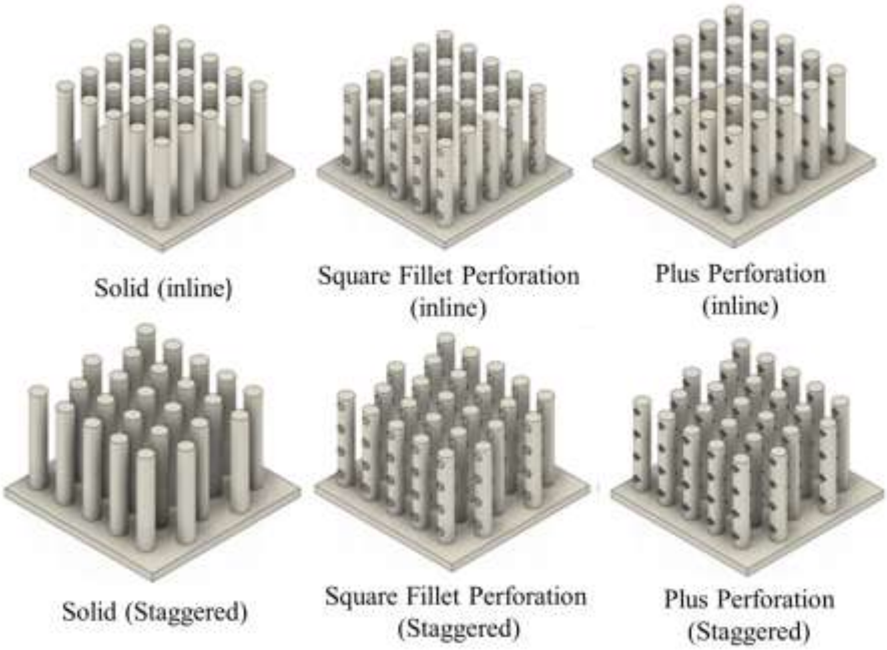


Figure 1. Design Shape Variations

Based on Figure 1, all variations use the same base plate size with dimensions of 110 mm x 110 mm x 5 mm. The pin diameter used is 10 mm and has a height of 60 mm and a distance between pins of 20 mm. The number of pins used is 25 pieces in each variation and has two arrangements, inline and staggered. The solid variation has a surface area of 73523.89 mm^2, the square fillet perforation variation has a surface area of 84776.38 mm^2, and the plus perforation variation has a surface area of 87011.83 mm^2. The solid variation has a plain design with no voids and no perforations. The perforation variations, square fillet perforation and plus perforation, have a total of 100 perforations. Testing is carried out on a channel with dimensions of 25 cm x 13 cm x 8 cm and uses an incoming air velocity on the inlet side with a speed of 4 m/s. This simulation test uses a heat source of 50 W which is located under the heat sink. The heat source used has dimensions of 90 mm x 90 mm x 5 mm and is in direct contact with the heatsink. In addition, this simulation is carried out with a stationary analysis or in other words, the variable has no effect on time (steady-state). An overview of the tests carried out can be seen in detail in Figure 2.

The base plate in each variation serves as a critical component for dissipating heat, with its dimensions and material properties directly influencing the thermal performance. The inline and staggered pin arrangements are designed to test different airflow dynamics and heat dissipation efficiency. The surface area differences between the solid and perforated variations indicate varying levels of thermal conductivity, with perforations potentially enhancing heat transfer by increasing the surface area exposed to airflow. The simulation environment, with specified channel dimensions, aims to replicate real-world conditions, ensuring accurate and reliable results. The choice of a 50 W heat source ensures that the tests are sufficiently rigorous to evaluate the thermal performance of each variation effectively.

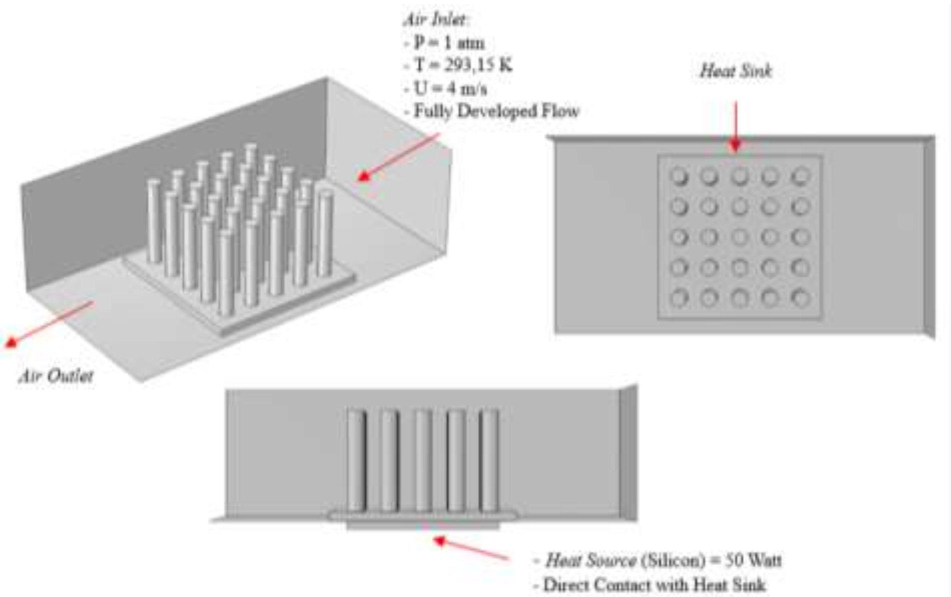


Figure 2. Overview of Heat Sink, Chip, Inlet, and Outlet Positions on the Channel

2.2 Material Properties

Heat sink material variations used include aluminum, copper, and iron. The material properties used are material properties based on data available in Comsol Multiphysics software. This data includes thermal conductivity, density, and specific heat capacity of each material used. The material properties used are as shown in Table 1 below:

Table 1. Material Properties [4].

No.	Material	Density	Thermal Conductivity	Heat Capacity
1.	Alumunium	2700 kg/m^3	238 W/m. K	900 J/kg. K
2.	Copper	8960 kg/m^3	400 W/m. K	385 J/kg. K
3.	Iron	7870 kg/m^3	76.2 W/m. K	440 J/kg. K

3. Result and Discussion

The results and discussion on simulation tests carried out in six variations of solid and perforated heat sinks are as follows:

3.1 Grid Independency Test Result (GIT)

The GIT results are used to determine the grid size that has the most efficient result accuracy by considering computation time. Based on Figure 3, it can be seen that the results of the normal grid size are not so far from the results of the fine grid size and looking at the computation time in Table 2, the fine grid size almost has twice the computation time of the normal grid size, so considering the results and computation time, simulation testing was carried out using the normal grid size.

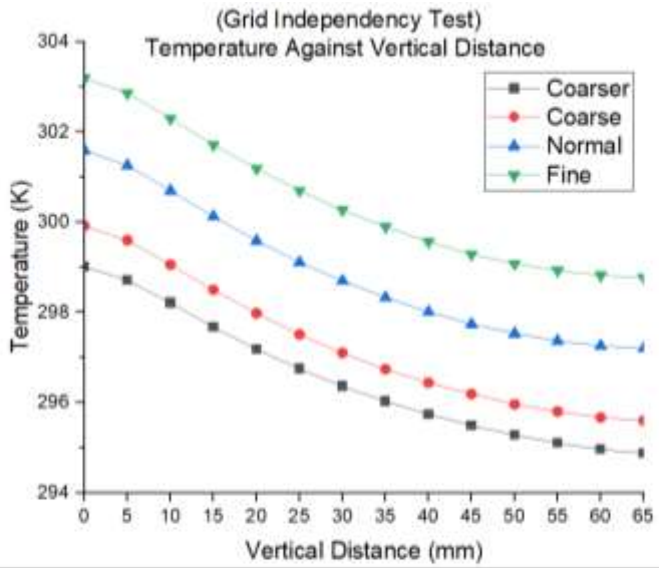
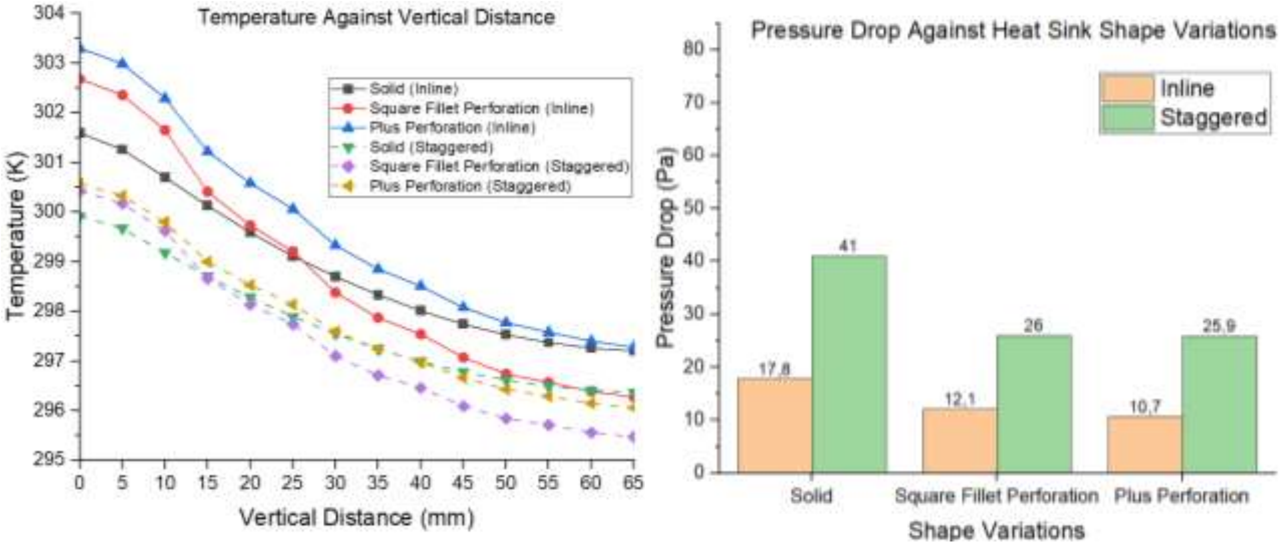


Figure 3. Grid Independency Test Result

Table 2. Comparison of Element Size with Computation Time

No.	Element/Grid Size	Computation Time
1.	*Coarser*	3 Minute 50 Second
2.	*Coarse*	7 Minute 20 Second
3.	Normal	1 Hour 46 Minute
4.	*Fine*	3 Hour 27 Minute



(a) **(b)**

Figure 4. a) Temperature Against Vertical Distance, b) Pressure Drop Against Heat Sink Shape Variations

3.2 Temperature Against Vertical Distance

Based on Figure 4a, the inline arrangement obtained the best temperature reduction performance by variations in the shape of the square fillet perforation, with the ability to reduce the temperature by 6.41 K, from 302.68 K to 296.27 K. In the staggered arrangement, the best temperature reduction performance was obtained by variations in the shape of the square fillet perforation, with the ability to reduce the temperature by 4.96 K, from 300.43 K to 295.47 K. The results obtained are in accordance with the research reference conducted by Amer Al-Damook et al, 2016 which states that perforations on the heatsink pin help improve thermal performance, especially in increasing heat transfer to air [5]. When compared based on the arrangement with variations in the shape of the fillet square perforation, it can be seen that the temperature drop value of the inline arrangement is much greater and better with a value of 6.42 K compared to the staggered arrangement with a value of 4.96 K. These results are supported by research references conducted by Shrenikkumar Oswal et al, 2015, which states in the conclusion of their research that better heat transfer performance occurs in pin heatsinks with an inline arrangement compared to a staggered arrangement [6]. Overall, the fillet square perforation shape variation obtained the best temperature reduction in the inline arrangement and staggered arrangement. Meanwhile, when viewed based on the arrangement, the inline variation obtained the best in terms of temperature reduction so that it was found that the variation of the shape of the fillet square perforation with an inline arrangement was the best variation.

3.3 Pressure Drop

Based on Figure 4b, the solid variation obtained the highest pressure drop value with a value of 17.8 Pa. The square fillet variation takes second place with a pressure drop value of 12.1 Pa and the perforation plus variation obtained a pressure drop value of 10.7 Pa. The same results were also seen in the staggered arrangement variation, the solid shape obtained a higher pressure drop than the other shapes, with a value of 41 Pa. The perforation shape obtained a pressure drop value that was not so far from each other, with the square plus shape obtaining a slightly better value than the square fillet perforation, which amounted to 25.9 Pa and 26 Pa. This is in accordance with the research reference conducted by Tijani et al, 2018, which states in the study that the perforation on the heat sink pin obtained a lower pressure drop than the solid shape variation [7]. When viewed based on the arrangement, it can be seen that the inline arrangement obtained a lower pressure drop than the staggered arrangement. It can be seen from the three variations of pin shape, the inline arrangement obtained a smaller value than the staggered arrangement. These results are also supported by research conducted by Sharath et al, 2018 and Ambarish Maji et al, 2017, which compares the performance of heat sinks between inline arrays and staggered heat sinks and states in the conclusion of their research that staggered arrays have a higher pressure drop than inline arrays [8], [9]. Overall, it can be concluded that the shape variation that has perforations obtains a lower pressure drop than the variation that does not have perforations and when viewed based on the arrangement, the inline arrangement form obtains a better pressure drop than the staggered arrangement.

3.4 Thermal Boundary Layer Result

Thermal boundary layer aims to see the phenomenon of temperature distribution across the surface of the heat sink in the form of a three-dimensional display as shown in Figure 5.

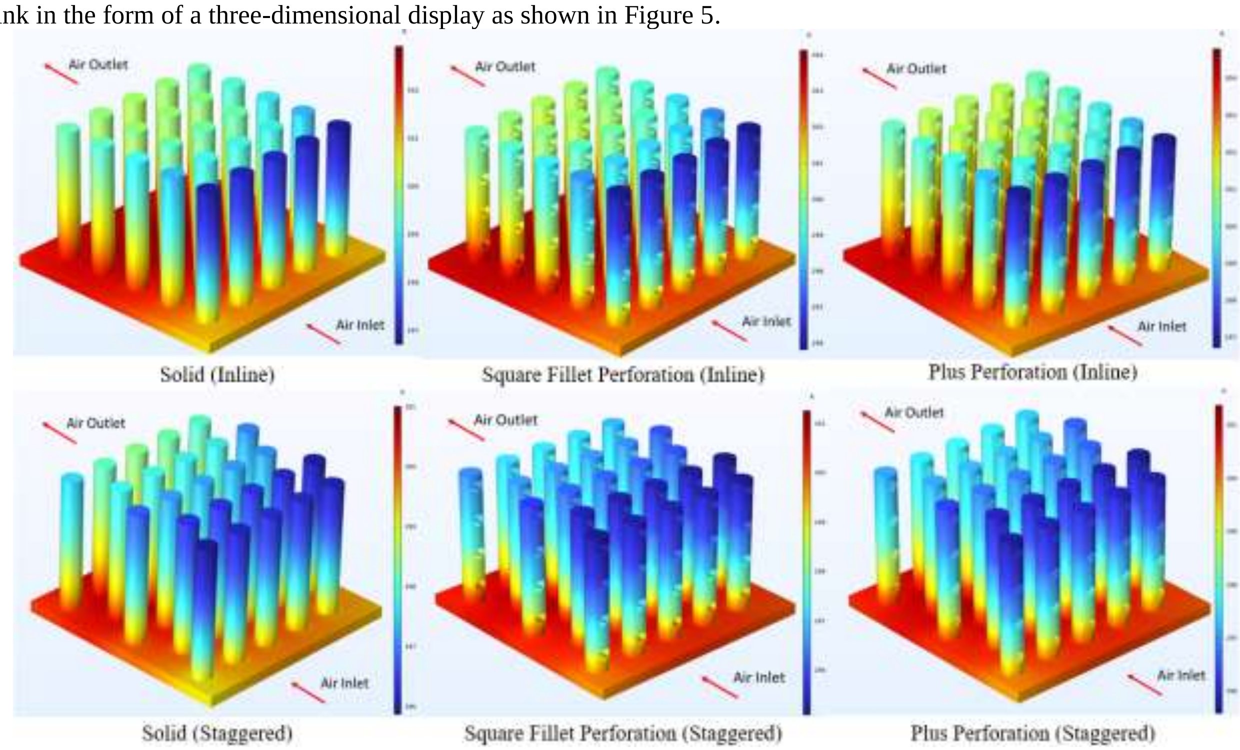


Figure 5. Thermal Boundary Layer

Based on Figure 5, it is indicated that the maximum temperature or hot region occurs at the bottom of the heat sink, while the minimum temperature or cold region occurs at the top surface of the heat sink. This shows that the closer to the heat source, the temperature will increase and the further away from the heat source the temperature will decrease. It can also be seen that the variation in the shape of the square perforation fillet inline arrangement obtains the coolest temperature in the upper surface area compared to other variations with a value of around 296 K. Another thing that can be seen is that the plus perforation shape in the inline arrangement obtains the highest maximum temperature in the base area of the heat sink, especially on the outlet side compared to other shape variations with a value of around 304 K. It can be seen in the staggered arrangement that the variation that has perforations has a cooler temperature on all parts of the pin, especially on the upper surface of the heat sink compared to the solid shape variation [10]. The upper surface temperature becomes the coldest point on the pin heatsink, with the variation of the square fillet perforation shape obtaining the smallest temperature compared to other shape variations, which is almost close to 295 K. Meanwhile, the largest maximum temperature at the base of the heat sink is obtained by the variation of the plus perforation shape with a value of around 300.5 K. Overall, the phenomenon formed is in accordance with one of the studies conducted by Aashish Kumar et al, 2018 and Nabeel Abdulhadi et al, 2021 which also analyzes the thermal boundary layer in solid and perforation variations. In his research, a picture is attached which has more or less the same temperature distribution as the research conducted by the author [2, 11].

3.5 Velocity Boundary Layer Result

Based on Figure 6 in the inline arrangement, the velocity contours of the airflow flowing past the heat sink almost have the same contour. The difference that occurs in the solid variation only occurs between two pins, with the first row to the second row the air velocity increases due to the narrowing of the flow area and begins to decrease until the last row of pins. The difference that occurs in the perforation variation, lies in the velocity passing through the perforation and the velocity between the two pins. The velocity passing through the perforation initially has a high speed, especially in the first row of pins and decreases until the last row of pins. The velocity between the two pins is slightly different from the solid variation, in the perforation variation the high speed between the two pins lasts longer until almost the last row of pins. In the staggered arrangement, it creates a more complicated flow. Seen in the solid variation, the velocity pattern is almost uniform on each pin from the initial row to the final row. In contrast to the perforation variation which has a high velocity in the perforation section in the first and second rows, with the second row having a higher velocity than the first row. This can be explained by the principle of continuity in fluid flow which reads "the fluid discharge flowing at each point along the flow is constant or the same" [12]. Overall, the phenomenon formed is in accordance with the research references conducted by Biswaranjan Pati et al, 2018 and Mushtaq Hasan, 2014, which in their research analyzed the velocity boundary layer in the inline arrangement and produced velocity contours that were more or less the same as the results of the research the authors did [13, 14].

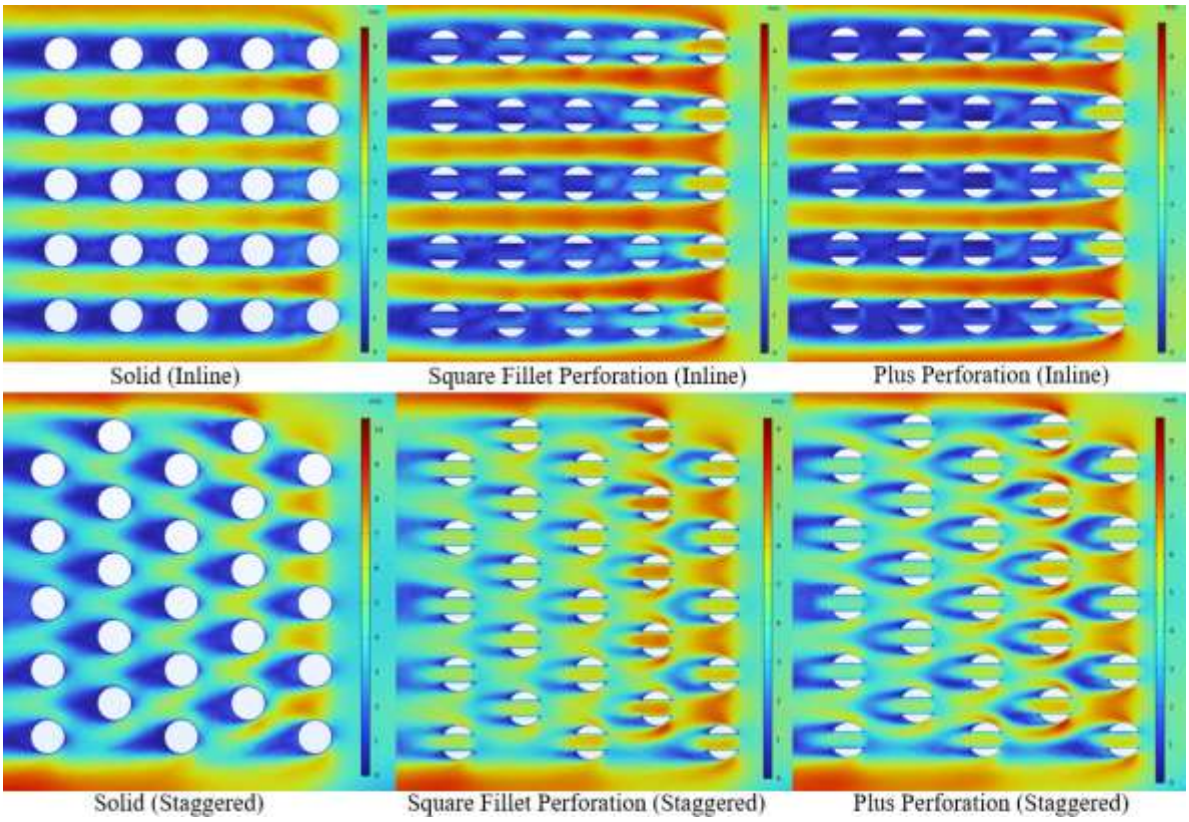


Figure 6. Velocity Boundary Layer

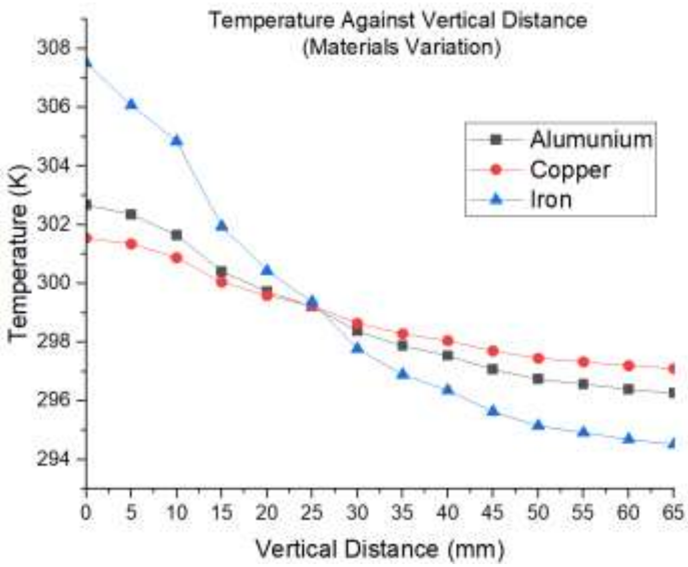


Figure 7. Temperature Against Vertical Distance (Material Variation)

3.6 Temperature Against Vertical Distance (Material Variation)

Unlike the previous analysis that used the most temperature drop as the best variation, in this material variation, the analysis used to determine the best material is to see how evenly the heat is distributed. Based on Figure 7, iron material experienced a significant decrease with a value of 95.7% decrease from the initial temperature. The aluminum material type looks better than the iron material type with a decrease value of 97.8% from the initial temperature.

Copper material was named the best type of material in this simulation test with the best temperature distribution of aluminum and iron materials, with the acquisition of a temperature drop value of 98.5% of the initial temperature. The results obtained in this study are in accordance with the research reference conducted by Mohsen Zaretabar et al, 2017 which also conducted tests with two materials, namely aluminum and copper. Based on these tests, the copper material obtained the most stable temperature from the base to the tip of the pin [15].

4. Conclusion

Copper is the best type of material in this simulation test with a temperature drop of 98.5% from the base temperature of the heat sink. Thermal boundary layer in the inline arrangement does not really show a significant difference from each other, the visible difference is the maximum temperature and minimum temperature. The thermal boundary layer in the staggered arrangement shows a difference in temperature at the end of the heat sink pin row, with the solid variation obtaining a higher temperature than perforation variation. The velocity boundary layer in the inline arrangement shows the difference in flow velocity contours between the two pins, with the square fillet perforation and perforation plus variations almost having a high velocity until the final row while in the solid only reaches the second row of pins. The velocity boundary layer in the staggered arrangement shows differences in the pattern of high velocities in the perforation section in the first and second rows, with the second row having a higher velocity in the than the first row. The plus perforation shape variation obtained the smallest pressure drop in the inline arrangement with a value of 40.1 Pa, while the fillet square perforation shape variation obtained the smallest pressure drop in the staggered arrangement with a value of 57.2 Pa. Based on the final results of the study, the fillet square perforation variation with an inline arrangement and copper material obtained the best design form than other design forms.

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