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Cold Plate Heat Sink with Different Fin Shapes Using Ansys Icepak

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Abstract:- The cooling of high-power electronic devices is crucial to ensure reliable operation and longevity. One promising method for cooling is the liquid jet impingement technique. In this study, the CFD method with ANSYS ICEPAK software is used to investigate the A cold plate heat sink with various fin shapes is cooled using a liquid jet impingement method. The purpose of the study is to assess the thermal performance of four different fin shapes, including rectangular, square, pentagonal, and hexagonal, and to look into how the cold plate heat sink's thermal performance is impacted by the fin geometry, fin spacing, and distance between the tip of the nozzle and the tips of the fins. The simulations are carried out with water as the cooling fluid, assuming laminar flow with a velocity of 2 m/s. The results show that the hexagonal and square fin shapes exhibit better thermal performance than pentagonal and rectangular fin shapes. The results of this study can be utilized to design efficient cooling systems for electronic devices in various industries, such as automotive, aerospace, and computer industries. The combination of the CFD method with ANSYS ICEPAK software provides a powerful tool to investigate the thermal behaviour of electronic devices and optimize their cooling systems.

Keywords*:* liquid cooling, heat transfer, cold plate, heat sink, Jet Impingement.

1. Introduction

Investigating heat transfer on flat and concave plate fin heat sinks with impingement air cooling, as well as jet array impingement, is crucial for various engineering applications, particularly in thermal management systems for electronics, aerospace, and automotive [1] H.Y. Zhang's work seems to focus on investigating the effects of various elements on thermal resistance, particularly in the context of heat sink design. This includes factors such as heat sink arrangement, fin size (both height and width), and the distance between the nozzle and fin tip in impingement cooling systems.[2] Development and investigation of cooling methodologies for dissipating the heat generated by high-power electronic applications. The increasing heat dissipation requirements of components like IGBTs, high-power transistors, LEDs, inverters, and supercomputers necessitate advancements in cooling techniques to prevent overheating and potential system failures. The passage highlights the importance of improving cooling methodologies to reduce thermal resistance and extend the lifetime of electronic components. Jet impingement cooling is specifically mentioned as one such technique that has been developed and employed over the last decade. In jet impingement cooling, a high-velocity fluid jet is directed onto the surface of a heated target, creating a thin boundary layer and enhancing convective heat transfer. By varying parameters such as the number of jets and the distance-to-diameter ratio (H/D), they aim to understand how these factors influence cooling performance and thermal resistance. [3,4]

The design, optimization, and practical applications of micro-channel heat sinks cooled by single-phase liquid and explores the potential benefits of jet impingement cooling in both electronic and industrial cooling systems.[5].

This research sounds comprehensive and detailed investigating the thermal performance of cold plate heat sinks with various fin shapes using ANSYS ICEPAK software, the study aims to provide valuable insights into designing efficient cooling systems for high-power electronic components.

Considering factors such as temperature distributions, velocity profiles, and pressure drops. This approach enables researchers to evaluate the effectiveness of different fin shapes in enhancing heat dissipation and optimizing thermal performance. The dimensions and operating conditions provided for the cold plate heat sink, including its total thickness, width, length, inlet velocity, and mass flow rate, are crucial for accurately simulating and analyzing the system's behavior. The laminar flow regime assumption and steady-state conditions ensure a simplified yet realistic representation of the fluid dynamics and thermal behavior within the heat sink. By comparing the results obtained for each fin shape, the study aims to identify the optimal design configuration that maximizes heat transfer efficiency and minimizes thermal resistance .The ultimate goal is to identify the maximizes heat dissipation fin shape and minimizes thermal resistance of the heat sink., Thus improving the efficiency and reliability of cooling systems for high-power electronic components. By providing actionable insights into the impact of fin geometry on thermal performance, the research contributes to the development of more effective cooling solutions tailored to the specific requirements of modern electronic devices.

2. Materials and Methods

2.1 Liquid Jet Impingement

A high-velocity liquid coolant is sprayed or jetted onto the surface of a heat sink as part of the cooling process known as liquid jet impingement. The surface of the heat sink is struck with great force by the liquid coolant, which is commonly water or another dielectric liquid. High heat transfer rates and effective cooling capabilities of liquid jet impingement make it a good choice for high-power electronic devices that need efficient heat dissipation as shown in Figure 1. To create turbulence and liquid jets that directly hit the fins of the cold plate heat sink, the liquid coolant is pressured and driven via nozzles or orifices as shown in Figure 2. High-velocity liquid jets strike the surface of the fins, creating laminar flow or turbulence and accelerating convective heat transfer. The heat from the fins is subsequently absorbed by the liquid coolant as it travels across the heat sink's surface and is then carried away. A protective vapor layer that insulates the heat sink surface from the liquid coolant is formed as the liquid coolant expands and changes phases, typically from liquid to vapor, as it absorbs heat. This vapor layer lowers the impedance of convective heat transmission, enabling effective heat transfer. The heated liquid coolant then moves away from the heat sink while carrying the heat that was absorb. A promising cooling method for high-power electronic equipment, liquid jet impingement's convective heat transfer mechanism permits quick and effective cooling of the heat sink surface.

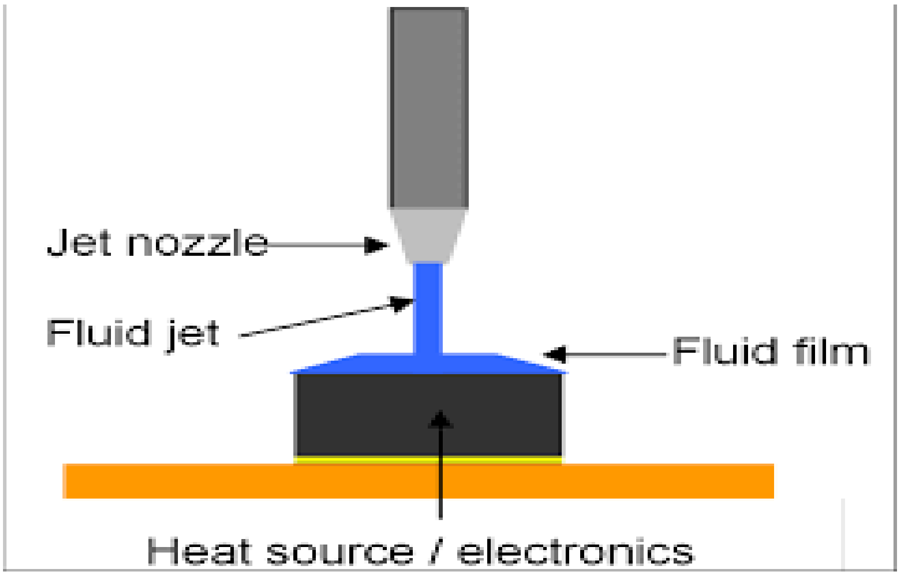

Figure. 1. Jet Impingement [Source 15]

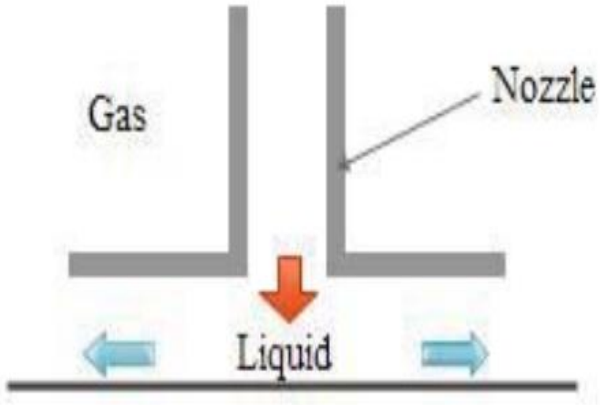

Figure. 2 Flow of Jet Impingement [Source 16]

2.2 Heat sink fin shapes

The shape of the fins in a heat sink is crucial for optimizing heat dissipation efficiency. Fins are the primary means by which heat is transferred from the heat sink to the surrounding environment, typically through convection. Different fin shapes offer varying degrees of effectiveness in maximizing surface area for heat transfer and promoting airflow.

One of the main benefits of using a liquid coolant in a cold plate heat sink is its high heat absorption capacity, which is significantly greater than that of air cooling. This high absorption capacity enables a cold plate heat sink to provide a higher cooling capacity, resulting in improved heat transfer from the electronic. A 3D computational model of the cold plate heat sink with several fin shapes (rectangular, square, pentagonal, and hexagonal) are created utilizing ANSYS ICEPAK. The model includes the fins and the impingement of the liquid jet. Analyzing the behavior of liquid flow and temperature transfer inside a cooling plate heat sink typically involves numerical simulations, such as computational fluid dynamics (CFD) modeling. Acquiring comprehensive outcomes including pressure drops, velocity profiles, and temperature distributions. Using water and nanofluids as the cooling media, the goal of this study is to evaluate the cooling effectiveness of a cold plate heat sink using liquid jet impingement with various fin shapes. The purpose of this research is to analyze the heat transfer properties of a heat sink subjected to a thermal load through the use of CFD simulation, specifically by examining the effects of a circular array of air jets impinging on the heat sink. The primary objective is to ensure that the temperature of the component remains at an optimal level for efficient operation. To accomplish this, a conjugate heat transfer model is utilized in conjunction with an SST k-x model for simulating turbulence in ANSYS FLUENT. Shridhar S. Thakar.[7]; The application of jet impingement heat transfer enhancement has been utilized in various applications with different heating areas and heat fluxes, due to the turbulent air and water jet impingement processes. [8-9]. This study focus on the use of the computational fluid dynamics (CFD) method using ANSYS ICEPAK software for analysing the cooling performance of a cold plate heat sink with multiple fin shapes, including rectangular, square, pentagonal, and hexagonal shapes. The CFD method is a powerful tool for analyzing the behavior of fluids and heat transfer in complex systems such as cold plate heat sinks, and ANSYS ICEPAK software is a widely used tool for performing CFD simulations. To begin the analysis, a 3D model of the cold plate heat sink with rectangular, square, pentagonal, and hexagonal fin shapes is created using CAD software as shown in Figures 3, 5, 7, and 9. The model is then imported into the ANSYS ICEPAK software, where a mesh is generated for each fin shape as show in Figures 4, 6, 8, and 10. In this study, the thermal properties of a cold plate made of aluminium and a heat sink made of copper have been analyzed under laminar flow conditions with water as the working fluid as shown in Table 1 . The Reynolds number is below 1300, indicating that the flow of water is in the laminar regime. The velocity of the fluid is 2 m/s, and the minimum temperature is 20 °C. The cold plate measures 45x45 mm in width and depth and 2 mm in height. The total cabinet dimensions are 64x16x64 mm. The fins measure 2 x 2 mm in width and depth and 6 mm in height, while the heat sink measures 50 x 50 mm in width and depth.

Table 1: Properties of the water at 20 °C

Properties name	Water
Thermal conductivity (k)	0.6 W/(m.K)
Density	1000 Kg/m3
Specific heat (Cp)	4180 J/(Kg.C)
Viscosity (μ)	0.001 Kg/(m.s)

The cold plate fluid width and depth are 49x49mm and a height of 8mm. The housing has a width and depth size of 60x60mm and a height of 12mm, while the heat source has a width and depth size of 30x30mm. The inlet diameter is 8mm, and both outlet 1 and outlet 2 have a diameter of 8mm. The inlet nozzle, outlet 1 and outlet 2 nozzles have a height of 4mm. The total number of fins in the X axis is 6 and in the Z axis is 6, resulting in a total of 36 fins. The study has been conducted us A numerically accurate simulation tool for a cooling plate heat sink, ANSYS displays the temperature and liquid flow behaviour.

The results of the study provide valuable insights into the thermal performance of the cooling plate heat sink with different geometries, which can be used to optimize the design of cooling systems for electronic components. The material properties of the cooling plate and the liquid flows through it are defined for each fin shape, and boundary conditions such as the inlet and outlet conditions for the fluid and the heat generation rate of the electronic components are set up. The solver settings for each fin shape are then specified, and the simulations are run using ANSYS ICEPAK software. During the simulations, the software solves the governing equations of fluid flow and heat transfer for each fin shape and generates a set of results. After the simulations are complete, the results are analyzed using ANSYS ICEPAK post-processing tools. The temperature, pressure, and velocity of the fluid are examined to understand the behavior of the fluid and the heat transfer process. The results for each fin shape are compared, and the optimal fin shape for the cold plate heat sink is determined.

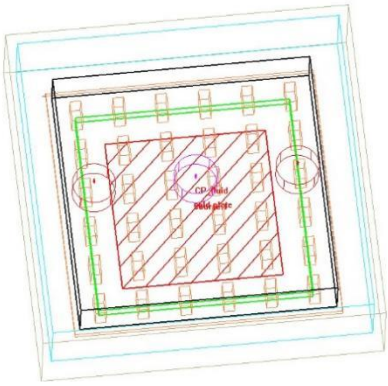

Figure. 3 Rectangular fin with heat sink

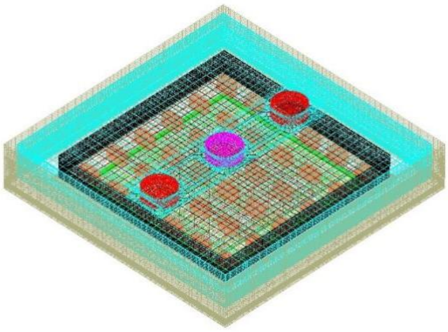

Figure. 4 Mesh

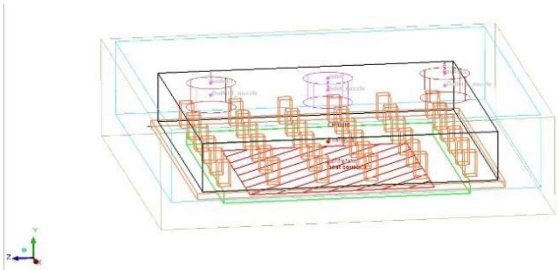

Figure. 5 Square fin with heat sink

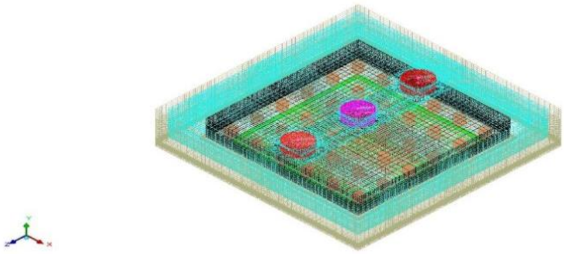

Figure. 6 Mesh

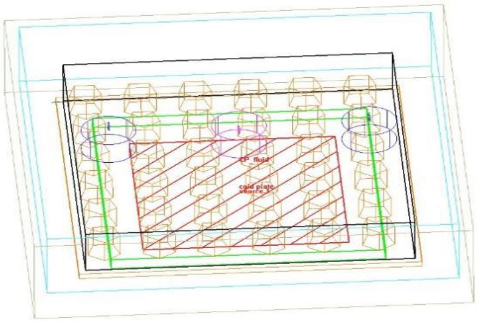

Figure. 7 Pentagonal fin with heat sink

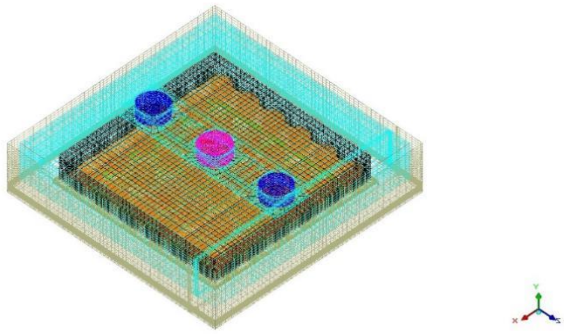

Figure. 8 Mesh

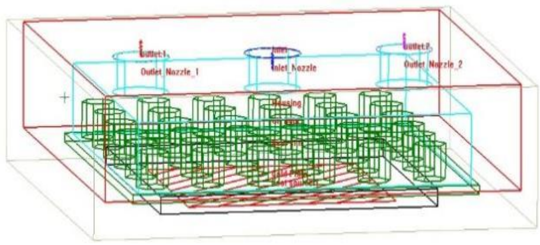

Figure. 9 Hexagonal fin with heat sink

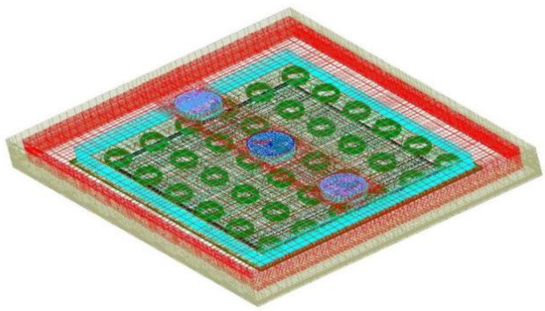

Figure. 10 Mesh

3. Results and Discussion

The research focuses on the use of a cooling element with liquid coolant in combination with jet impingement to improve heat removal. The configuration and design of the cooling element plays a crucial role in enhancing energy removal through conduction and convection processes. The study investigates heat transfer and fluid flow characteristics in a cold plate cooling element with different fin geometries. The test setup uses cooling elements of cold plates, which are usually made of highly thermally conductive materials such as aluminum or copper. The research examines different test conditions, including different heating frequencies, to evaluate the performance of the heat sink under different heat loads.

By studying the heat transfer and fluid dynamics in the heat sink, the research aims to optimize its design for efficient cooling of the heat sink. . radish high power electronic equipment. This could lead to advances in thermal management strategies, ultimately improving the reliability and performance of electronic systems in various applications.

The study used a cold flat heat sink composed of highly thermally conductive materials such as aluminum and copper. The test conditions included applying a heat rate of 100 W to heat sources of various sizes (30 x 30 mm) and a coolant mass flow rate of 0.183 kg/s. As part of the parametric studies, different fin geometries were investigated. The cooling efficiency of the device was assessed by monitoring temperature rise over time and validating the speed response of the cooling accuracy values. As expected, the average thermal resistance decreased with increasing coolant flow rate. Rectangular, square, pentagonal, and hexagonal pin fin configurations were analyzed for their effects on temperature distribution and pressure. The study revealed the following results. Rectangular pin fin configuration: Temperature distribution of 28.76°C and pressure of 3289.88 N/m^2. Square pin fin configuration: Temperature distribution of 28.6464°C and pressure of 3234.85 N/m^2. Pentagonal pin fin configuration: Temperature distribution of 29.081°C and pressure of 3233.13 N/m^2. Hexagonal pin fin configuration: Temperature distribution of 27.137°C and pressure of 3279.73 N/m^2. Furthermore, the study examined the effects of pin fin configurations on the temperature distribution across the cold plate heat sink. It was observed that the hexagonal pin fin heat sink exhibited the highest temperature due to its increased scrubbing flow. The findings suggest that optimizing the design of the cold plate heat sink, particularly by utilizing hexagonal fin shapes, can significantly enhance cooling performance. This research contributes to improving thermal management strategies for high-power electronic devices, potentially leading to more efficient and reliable electronic systems in various applications.

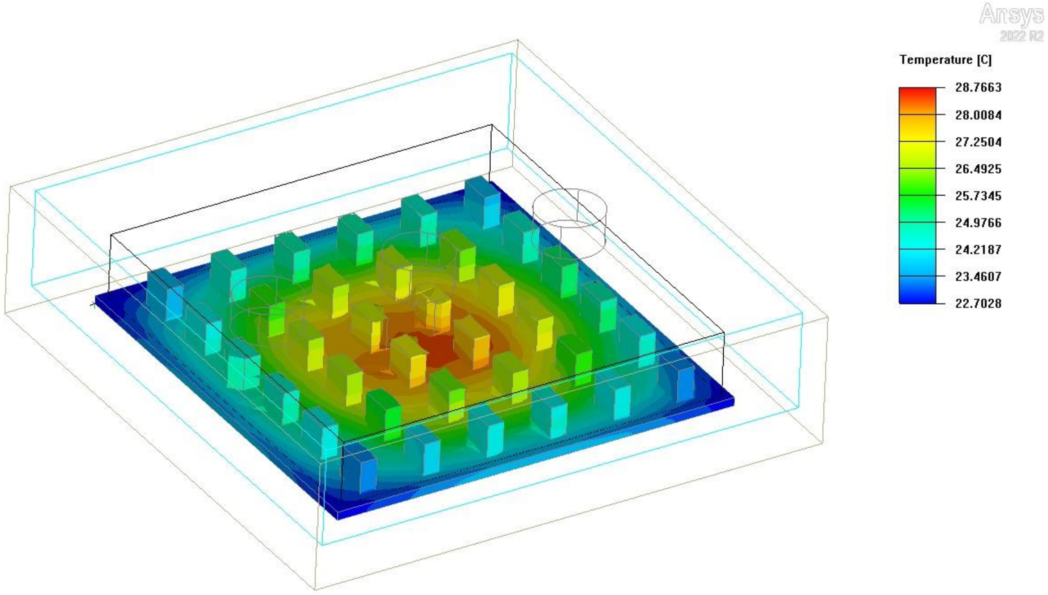

Figure. 11 Temperature in the Rectangular fin with heat sink

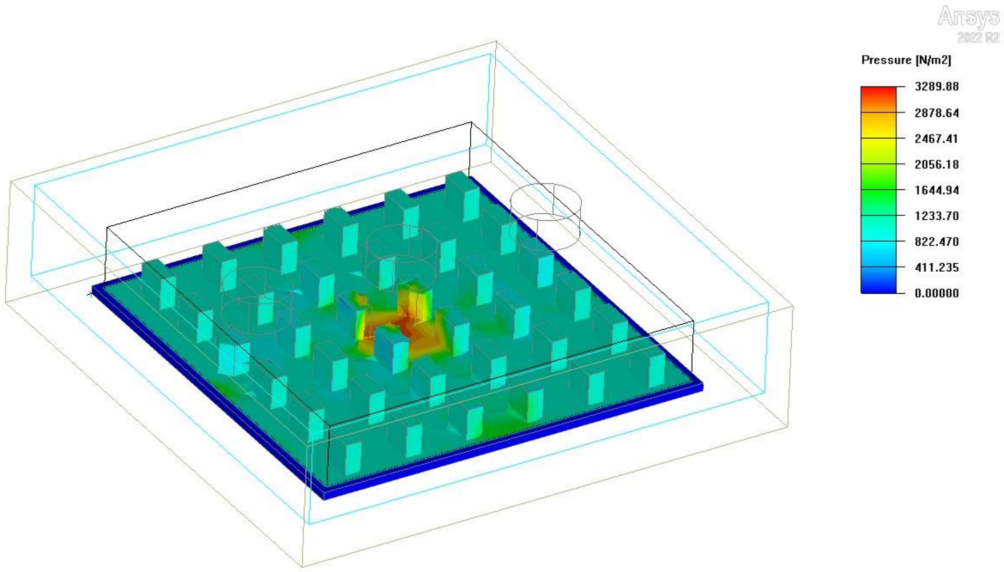

Figure. 12 Pressure in the Rectangular fin with heat sink

Table 2: Rectangular Shape Temperature Difference (°C)

Surface shape	Min (°C)	Max (°C)
Inlet	20	20.6995
Outlet 1	20.1037	21.3135
Outlet 2	20.183	21.3592
Heat sink	22.7028	28.7663
Cold plate	24.2174	29.6233

Table 3: Rectangular Shape Pressure Difference (N/m2)

Surface shape	Min (°C)	Max (°C)
Inlet	20	20.6995
Outlet 1	20.1037	21.3135
Outlet 2	20.183	21.3592
Heat sink	22.7028	28.7663
Cold plate	24.2174	29.6233

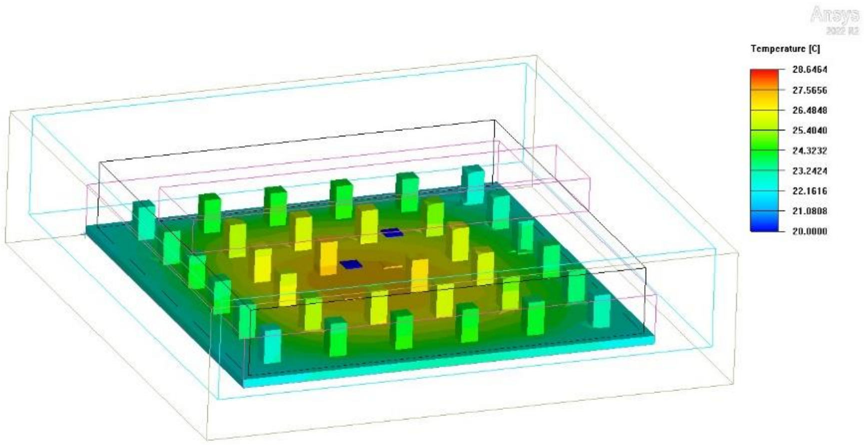

Figure. 13 Temperature in the Square fin with heat sink

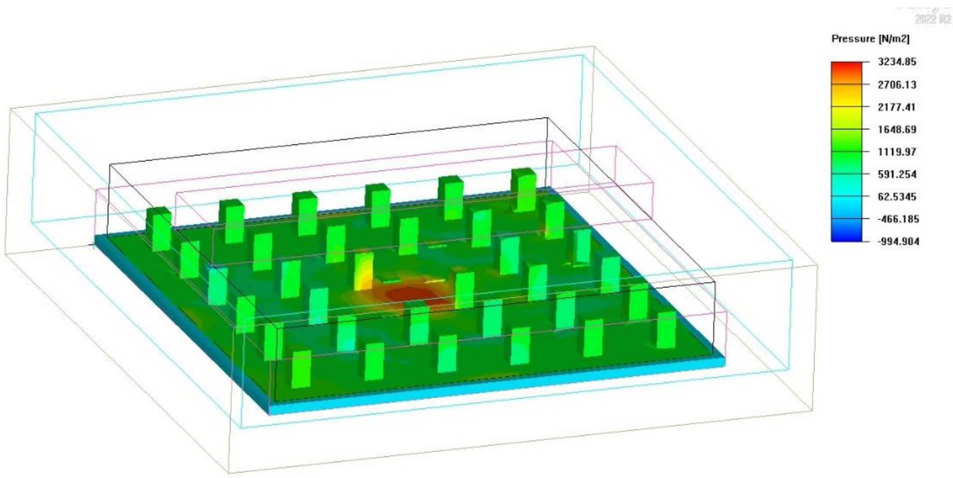

Figure. 14 Pressure in the Square fin with heat sink

Table 4: Square Shape Temperature Difference (°C)

Surface shape	Min (°C)	Max (°C)
Inlet	20	20.7156
Outlet 1	20.1887	21.206
Outlet 2	20.1849	21.1999
Heat sink	20.1969	27.7991
Cold plate	23.4088	28.6464

Table 5: Square Shape Pressure Difference (N/m2)

Surface shape	Min (N/m2)	Max (N/m2)
Inlet	1256.23	1272.34
Outlet 1	-8.6886	42.2366
Outlet 2	-9.10858	39.9371
Heat sink	0	3234.85

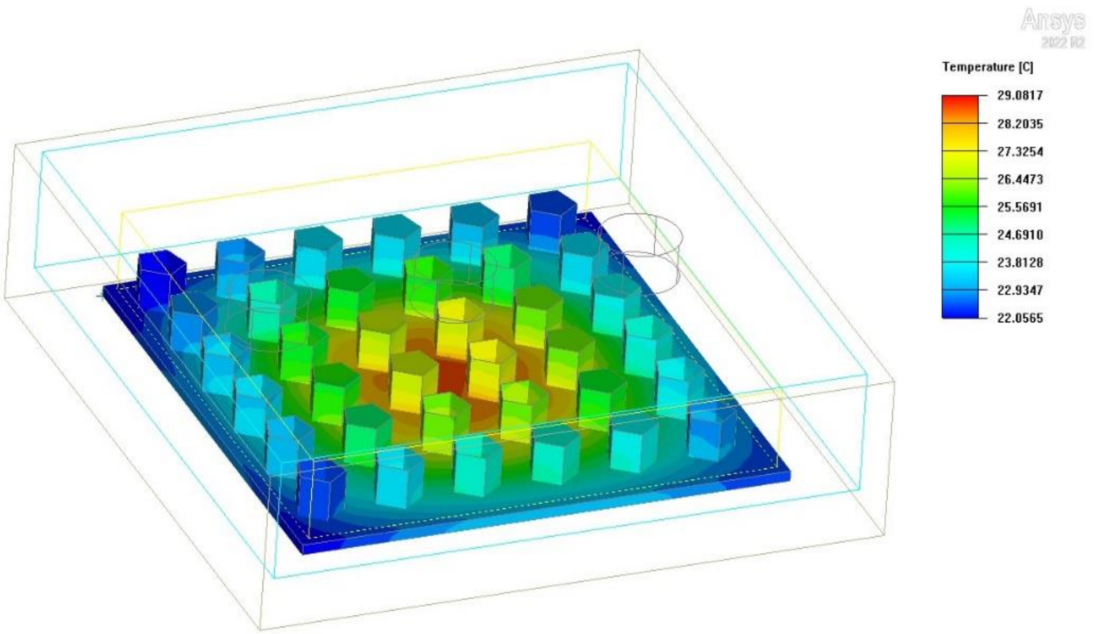

Figure. 15 Temperature in the Pentagonal fin with heat sink

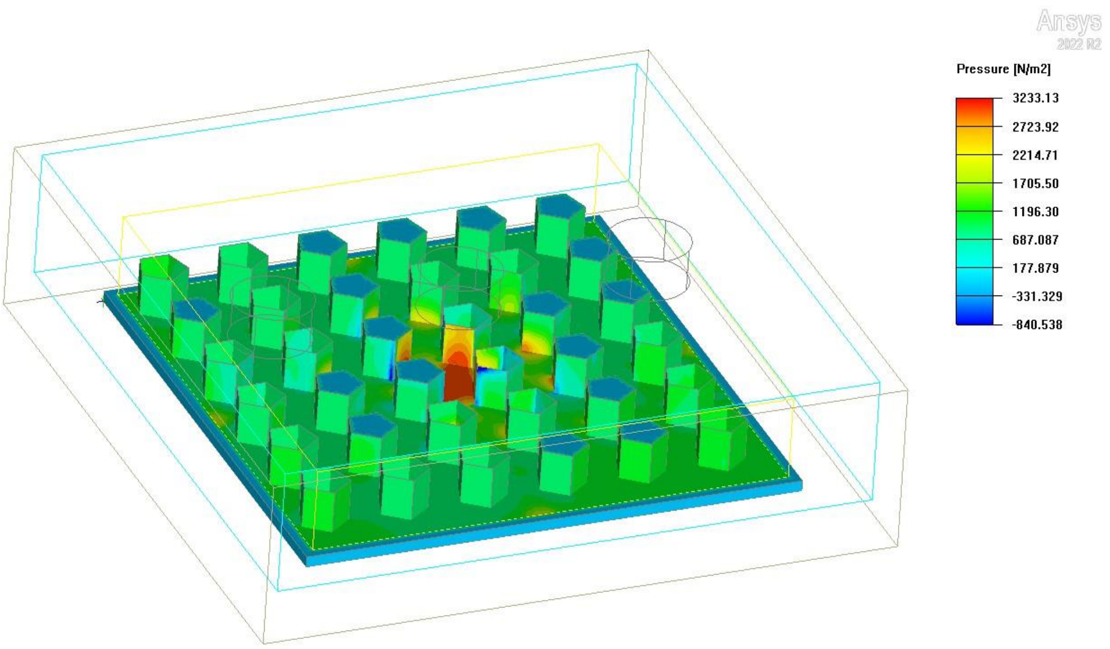

Figure. 16 Pressure in the Pentagonal fin with heat sink

Table 6: Pentagonal Shape Temperature Difference (°C)

Surface shape	Min (°C)	Max (°C)
Inlet	20	20.6671
Outlet 1	20.1973	21.0276
Outlet 2	20.1935	21.1967
Heat sink	22.0565	29.0817
Cold plate	23.2719	29.861

Table 7: Pentagonal Shape Pressure Difference (°C)

Surface shape	Min (N/m2)	Max (N/m2)
Inlet	1226.25	1252.68
Outlet 1	-3.85903	62.0111
Outlet 2	-6.0377	60.2283
Heat sink	-840.538	3233.13

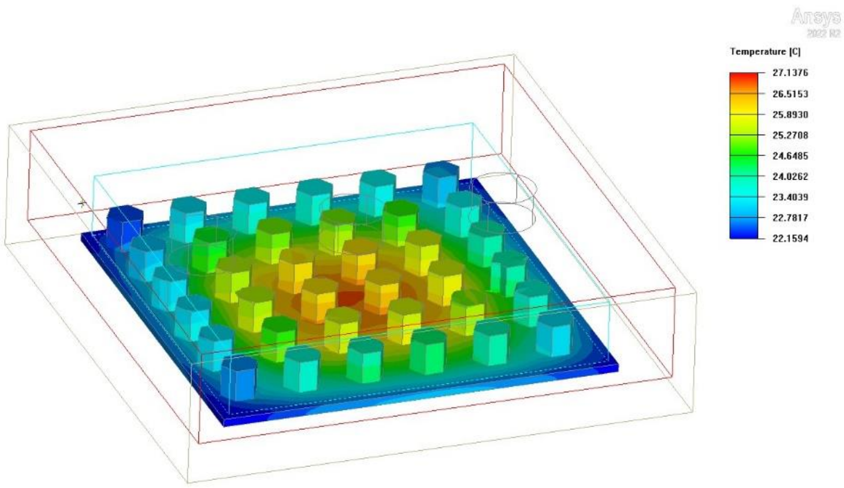

Figure. 17 Temperature in the Hexagonal fin with heat sink

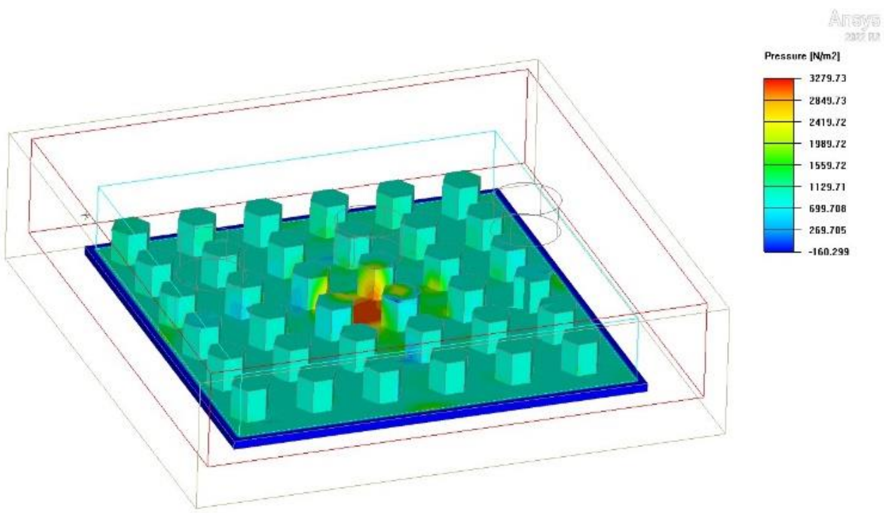

Figure. 18 Pressure in the Hexagonal fin with heat sink

Table 8: Hexagonal Shape Temperature Difference (°C)

Surface shape	Min (°C)	Max (°C)
Inlet	20	20.59
Outlet 1	20.165	21.0096
Outlet 2	20.1801	21.0558
Heat sink	22.1594	27.1376
Cold plate	23.2553	27.9808

Table 9: Hexagonal Shape Pressure Difference (°C)

Surface shape	Min (N/m2)	Max (N/m2)
Inlet	1249.79	1270.83
Outlet 1	-16.9522	47.8093
Outlet 2	-15.0788	38.494
Heat sink	-160.299	3279.73

The Reynolds number can be defined by the equation:

$Re = \rho VD/\mu$ (1)

where represents the fluid density, V represents the fluid velocity, D represents the pipe diameter, and represents the fluid viscosity.

The Prandtl number is defined by the equation:

$Pr = \mu Cp/k$ (2)

where Cp represents the specific heat of the fluid and k represents its thermal conductivity.

The Nusselt number is calculated by the formula:

$Nu = hD/k$ (3)

where h is the heat transfer coefficient, D is the diameter of the pipe, and k is the fluid's thermal conductivity.

The heat transfer coefficient using the fin equation, we can use the formula:

$$h = q/(A*(Tb - Ta)) \quad (4)$$

where q represents the heat transfer rate, A represents the surface area of the fin, Tb represents the base temperature, and Ta represents the ambient temperature.

Finally, we can calculate the surface area of the fin by using the equation:

$A = L*m$ (5)

where L represents the length of the fin, and m represents its width, which depends on the fin's shape and material properties.

The efficiency of convective heat transmission between the fluid and the fin is indicated by a greater Nusselt number. The Nusselt numbers provided, the hexagonal fin shape has the high- est convective heat transfer coefficient (Nu = 22.333), followed by the rectangular fin (Nu = 18.3375), the pentagonal fin (Nu = 15.816), and the square fin (Nu = 14.6198). Therefore, for a given Reynolds number, the hexagonal fin shape would provide the highest heat transfer rate, while the square fin shape would provide the lowest heat transfer rate as shown in Figure 19 and Table 10.

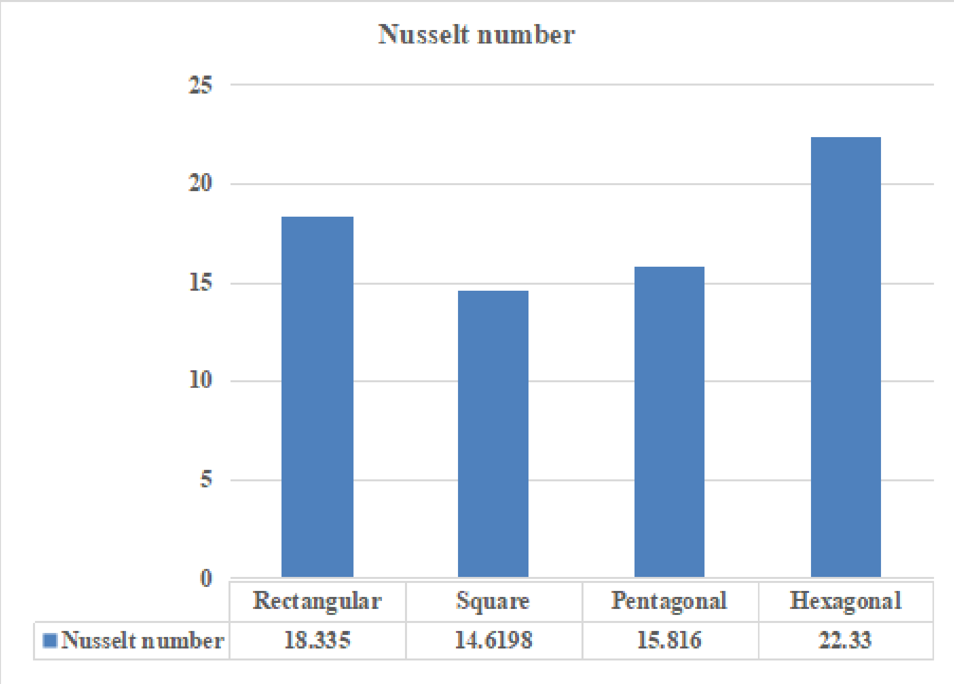

Figure. 19 Comparison of fin shapes in the heat transfer rate

Table 10: Comparison table of heat sink with fin shapes

Parameters	Rectangular fin	Square fin	Pentagonal fin	Hexagonal fin
Min Temperature (Tmin)	22.702 °C	20.1961 °C	22.0565 °C	22.1594 °C
Max Temperature (Tmax)	28.7663 °C	27.7991 °C	29.0817 °C	27.1376 °C
Pressure (P)	3289.88 N/m2	3234.85 N/m2	3233.13 N/m2	3279.73 N/m2
Convective heat transfer coefficient (h)	1375.1375 W/m2.C	1096.491 W/m2.C	1186.239 W/m2.C	1675.041 W/m2.C
Reynolds number (Re)	16000	16000	16000	16000
Nusselt number (Nu)	18.335	14.6198	15.816	22.333

4. Conclusion

The conclusion is that the hexagonal and square fin shapes have better cooling performance compared to the other fin shapes. The hexagonal fin shape provides the best cooling performance, followed closely by the square fin shape. The pentagonal and rectangular fin shapes have moderate cooling performance. The cold plate heat sink design was optimized using the ANSYS ICEPAK software, and the results demonstrate that the fin spacing significantly affects cooling performance. Fin spacing affects cooling performance; increasing fin spacing reduces cooling performance; reducing fin spacing increases cooling performance. In conclusion, the CFD method using ANSYS ICEPAK software provides a powerful tool for analyzing the cooling performance of a cold plate heat sink with different fin shapes. The results show that the hexagonal fin shapes provide the best cooling performance, and the optimization of the cold plate heat sink design can significantly improve the cooling performance. These findings have important implications for the design of thermal management solutions for electronic systems, where efficient cooling is essential for reliable and optimal performance.

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References

[1] Kiziroglou, M.E., Wright, S.W., Toh, T.T., Mitcheson, P.D., Becker, T. and Yeatman, E.M., 2013. Design and fabrication of heat storage thermoelectric harvesting devices. IEEE Transactions on Industrial Electronics, 61(1), pp.302-309.

[2] Pielichowska K, Pielichowski K. Phase change materials forthermal energy storage. Prog Mater Sci. 2014;65:67–123.

[3] Sarier N, Onder E. Organic phase change materials and their textile applications: an overview. Thermochim Acta. 2012;540:7–60.

[4] Chang SJ, Wi S, Jeong S, Kim S. Analysis on phase transition range of the pure and mixed-phase change materials (PCM) using a thermostatic chamber test and differentiation. J Therm Anal Calorim. 2017. https://doi.org/10.1007/s10973-017-6603-y.

[5] Li, X., Zhou, Y., Nian, H., Zhang, X., Dong, O., Ren, X., Zeng, J., Hai, C. and Shen, Y., 2017. Advanced nanocomposite phase change material based on calcium chloride hexahydrate with aluminum oxide nanoparticles for thermal energy storage. Energy & Fuels, 31(6), pp.6560-6567.

[6] Fortunato, B., Camporeale, S.M., Torresi, M. and Albano, M., 2012. Simple mathematical model of thermal storage with PCM. AASRI Procedia, 2, pp.241-248.

[7] Kumar, R.S. and Krishna, D.J., 2013. Differential scanning calorimetry (DSC) analysis of latent heat storage materials for low temperature (40–80 C) solar heating applications. Int. J. Eng. Res. Technol, 2(8), pp.429-455.

[8] Martínez, A., Carmona, M., Cortés, C. and Arauzo, I., 2020. Characterization of thermophysical properties of phase change materials using unconventional experimental technologies. Energies, 13(18), p.4687.

[9] Pujula, M., Sánchez-Rodríguez, D., Lopez-Olmedo, J.P., Farjas, J. and Roura, P., 2016. Measuring thermal conductivity of powders with differential scanning calorimetry. Journal of Thermal Analysis and Calorimetry, 125(2), pp.571-577.

[10] Mishra, A., Shukla, A., and Sharma, A., 2015. Latent heat storage through phase change materials. Resonance, 20(6), pp.532-541.

[11] Manickam, R., Kalidoss, P., Suresh, S., and Venkatachalapathy, S., 2019. Erythritol-based Nano-PCM for Solar Thermal Energy Storage. International Research Journal of Engineering and Technology (IRJET), 6, pp.1631-1636.

[12] Kumaresan G, Velraj R, Iniyan S. Thermal analysis of D-mannitol for use as phase change material for latent heat storage. Journal of Applied Sciences. 2011 Dec; 11:3044-8.

[13] Mondal, S., 2008. Phase change materials for smart textiles–An overview. Applied thermal engineering, 28(11-12), pp.1536-1550.

[14] Salinas, A., Altecor, A., Lizcano, M. and Lozano, K., 2016. Production of b-silicon carbide nanofibers using the force spinning method. J. Ceram. Sci. Tech, 7(03), pp.229-234.

[15] Salinas, A., Lizcano, M. and Lozano, K., 2015. Synthesis of β-SiC fine fibers by the force spinning method with microwave irradiation. Journal of Ceramics, 2015.

[16] Gil, A., Barreneche, C., Moreno, P., Solé, C., Fernández, A.I. and Cabeza, L.F., 2013. Thermal behavior of d-mannitol when used as PCM: Comparison of results obtained by DSC and in a thermal energy storage unit at pilot plant scale. Applied Energy, 111, pp.1107-1113.

[17] S. Mondal, " Phase change materials for smart textiles–an overview," Applied, thermal Engineering, vol. 28, no. 11-12, pp. 1536–1550, 2008.

[18] Kenisarin, M. and Mahkamov, K., 2007. Solar energy storage using phase change materials. Renewable and sustainable energy reviews, 11(9), pp.1913-1965.