Design And Optimization of An Impingement-Cooled Heat Sink Using CFD Approaches

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Abstract- *Impingement cooling method utilizes high speed jet(s) to impinge on a high temperature surface for cooling or heating. In this study, various heat sinks geo metrical configurations Heat sink with no fins, Heat sink with continuous plate fins, Heat sink with interrupted plate fins, Heat sinks with pin-fins were studied. The studies had been conducted for three jet velocity (2, 4 and 6 m/s) as well as three Z/d ratios of 2, 4 and 6. Numerical simulations for this work had been performed in ANSYS FLUENT with RNG k-ϵ turbulence model to account for the Reynolds Stresses. As high as 25% heat transfer enhancement was observed by employing pin-fins. The ineffectiveness of the plate fins both continuous and interrupted for the impingement cooling were attributed to obstruction to the flow path in these geo metrical variants. Also, the increase in the pin-fin diameter was resulted heat transfer enhancement.*

Keywords- Impingement cooling, Heat Sink, ANSYS fluent, CFD, Jet Velocity, Reynold Stresses, Heat Transfer.

I. INTRODUCTION

In the recent development of performance oriented electronic components, heat removal mechanisms play an important role in the longevity and sustained performance of these components. These high-performance electronic components like computer processors emits significant amount of heat due to high computational load on these devices. An efficient heat removal mechanism surrounding would ensure the surfaces of the electronic devices are in the acceptable temperature range.

There have been numerous heat removal methods that were implemented. These could be broadly classified in to the following;

- Natural Convection based heat removal methods
- Forced convection-based heat removal methods
- Impingement cooling method
  a) Free jet cooling
  b) Submerged jet cooling

II. OBJECTIVES OF THE WORK

The objectives of present work are: -

1. To review the existing literature related to impingement cooling mechanism.
2. A comparative study between the heat transfer performances of plainheat sink surface with the plate-finned heat sink will be conducted.
3. The impact of discontinuous finned heat sinks under the impingement cooling were to be investigated
4. The heat sink will be designed with the pin-fins. During this study, the fin diameter, fin height will be varied to study these parameter’s influence on the heat transfer rate from the impingement cooling method.

III. PROJECT PROBLEM DEFINATION

Under the impingement cooling mechanism, the existing heat sink model with hexagon shaped was to be optimized using CFD simulations. The most commonly applied fins are plate-fins – that has either square or rectangular cross section – or pin-fins that has circular cross-section. In order to identify the optimal heat sink model, the project work was conducted as per the following approach.

Stage 1: Heat Sink without fins

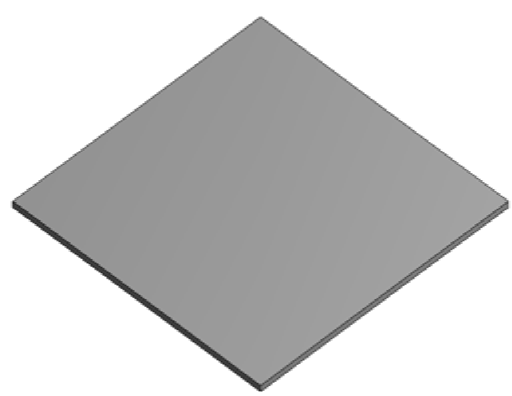

Fig. 3.1 Heat sink without any fins (Base Model)

Stage 2: Heat Sink with Plate-fins

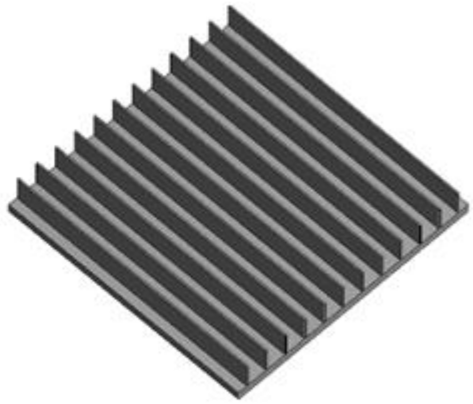

Fig. 3.2 Heat Sink with Plate-fins

Stage 3: Heat Sink with Pin-fins

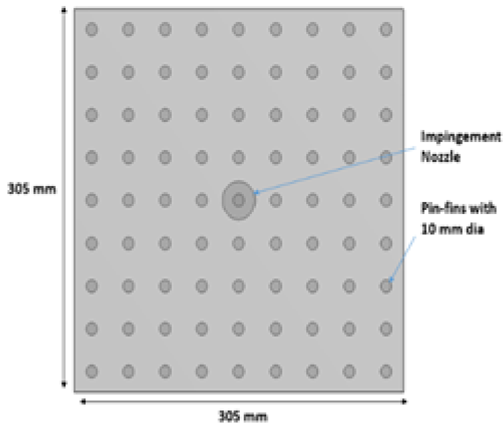

Figure 3. 3 Heat sink with Pin-fins

Jet Impingement Position and Its Impact on Heat Removal

In the jet impingement cooling mechanism, the heat sink would be placed at a distance from the impinging nozzle. Through the nozzle, the coolant, typically air, would be directed towards the heat sink. Upon the impingement, the coolant temperature will be increased due to the impact with the high temperature heat sink.

Various researchers had highlighted that the distance between the heat sink and the impinging nozzle(s) had an influence on the heat removal effectiveness of the system. Hence, this geometry parameter was also investigated in this project work. In order to quantify this parameter, the following approach had been applied.

- The nozzle diameter – D
- Normal distance between the heat sink and the nozzle – Z

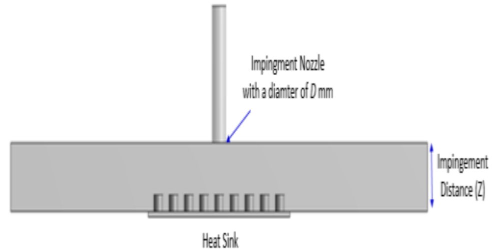

Fig. 3.4 General descriptions of the Impingement Cooling Assembly

- **Nozzle Positioning**

$$\alpha = \frac{Z}{D}$$

For this project work, three configurations α = 2, 3 and 4 was investigated to obtain the conclusions on the impact of nozzle positioning over the heat removal rate.

IV. NUMERICAL SIMULATIONS

Computational Fluid Dynamics (CFD) based engineering research work has been gaining popularity over the past decades. These methods have found applications in multiple domains such as aerospace, automotive, chemical processing, bio-medical engineering as well as electronics cooling. The computer-based simulations help in reducing product development time by obtaining the results faster and with the lesser cost as compared to the experimental studies.
This project work was carried out on the ANSYS WorkBench18.1 environment with many of its modules had been used. In general, the CFD simulations involve the following four major steps

- Geometry Creation
- Meshing
- CFD simulation
- Results Analysis.

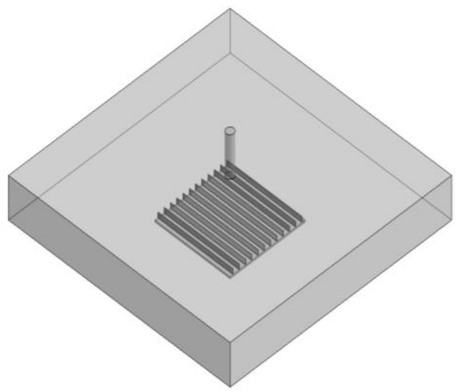

Fig 4.1 Impingement cooling geometry set-up

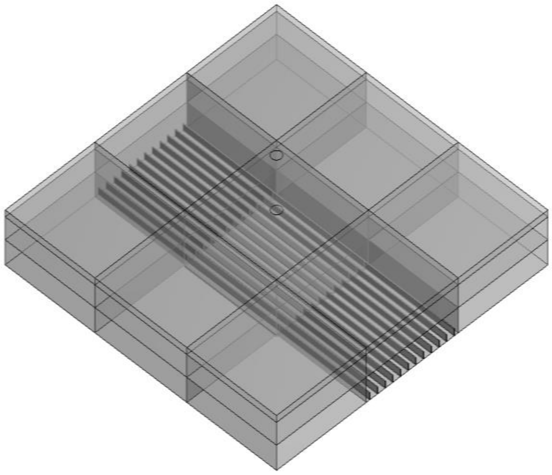

Fig 4. 2 Impingement cooling geometry set-up for meshing

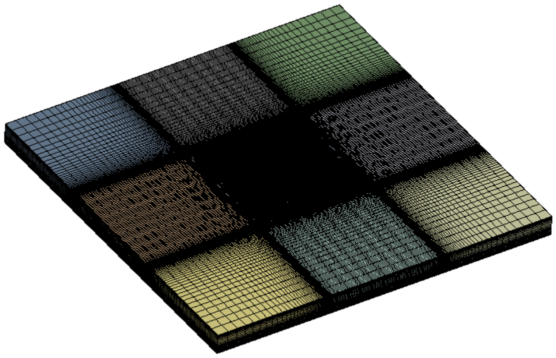

Fig. 4.3 Meshing for the impingement cooling set-up

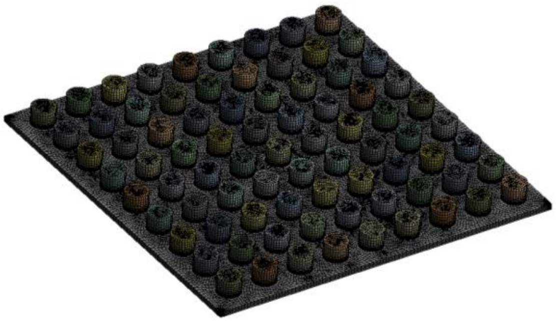

Fig. 4.4 Meshing for the pin-fin heat sink

V. RESULT AND DISCUSSION

Heat transfer rate comparisons for the Base Model Heat Sink

Z/d	Heat transfer rate, W		
	Jet Velocity 2 m/s	Jet Velocity 4 m/s	Jet Velocity 6 m/s
2	71.4	123.4	170
3	73.1	131.3	184.1
4	76.9	150.3	210.4

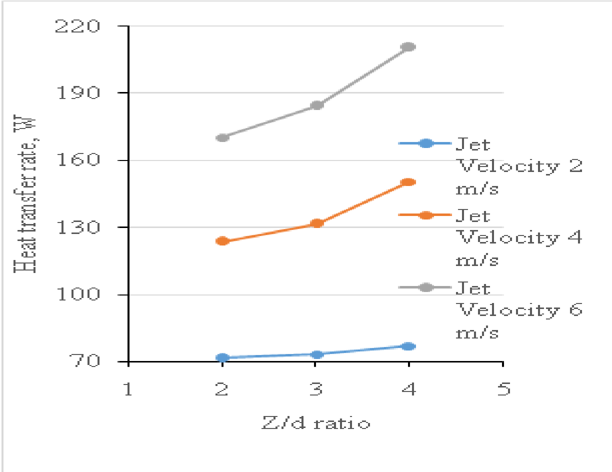

Fig.5.1 Heat transfer rate comparisons for the Base Model Heat Sink

Heat transfer rate comparisons for the Variant-1 Heat Sink

Z/d	Heat Transfer Rate, Watts		
	Jet Velocity 2 m/s	Jet Velocity 4 m/s	Jet Velocity 6 m/s
2	64	97.3	126.1
3	66.7	100.4	128.9
4	75	106	132.9

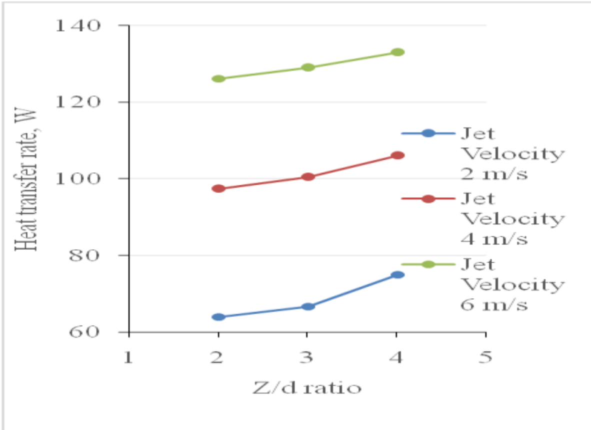

Fig. 5.2 Heat transfer rate comparisons for the Variant-1 Heat Sink

Heat transfer rate comparisons for the Variant-2 Heat Sink

Z/d	Heat transfer rate, W		
	Jet Velocity 2 m/s	Jet Velocity 4 m/s	Jet Velocity 6 m/s
2	90.6	146.7	189.4
3	91.6	146.1	189.0
4	99.4	159.1	204.3

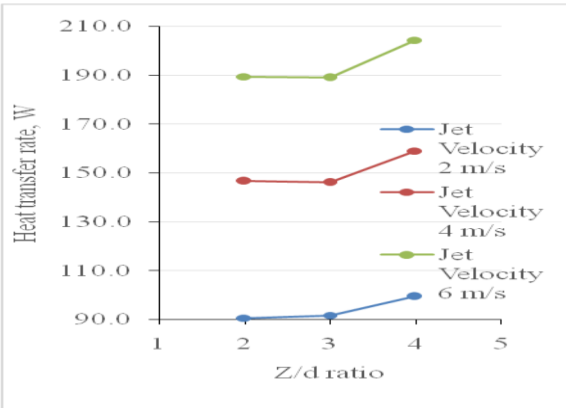

Fig. 5.3 Heat transfer rate comparisons for the Variant-2 Heat Sink

Heat transfer rate comparisons for the Variant-3 Heat Sink

Z/d	Heat transfer rate, W		
	Jet Velocity 2 m/s	Jet Velocity 4 m/s	Jet Velocity 6 m/s
2	81.3	140.7	203.4
3	86.4	161.2	237.5
4	88.3	171.3	238.4

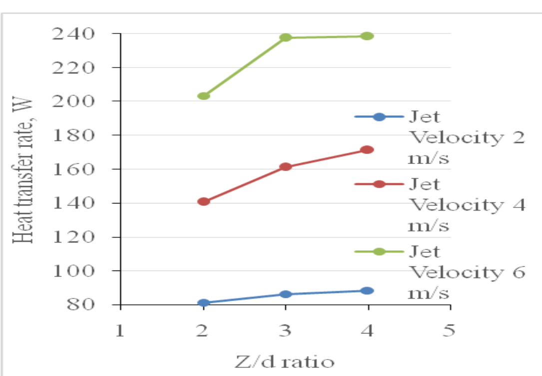

Fig 5.4 Heat transfer rate comparisons for the Variant-3 Heat Sink

Heat transfer rate comparisons for the Variant-4 Heat Sink

Z/d	Heat transfer rate, W		
	Jet Velocity 2 m/s	Jet Velocity 4 m/s	Jet Velocity 6 m/s
2	86.2	154.7	222
3	90.8	159.5	233.9
4	94.2	173	234.5

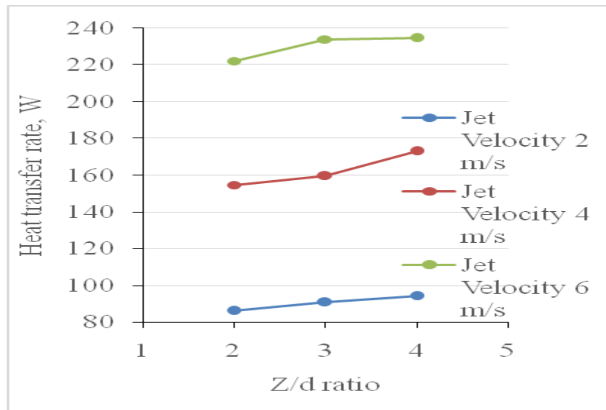

Fig. 5.5 Heat transfer rate comparisons for the Variant-4 Heat Sink

Heat transfer rate comparisons for the Variant-5 Heat Sink

Z/d	Heat transfer rate, W		
	Jet Velocity 2 m/s	Jet Velocity 4 m/s	Jet Velocity 6 m/s
2	85.5	152.6	211.5
3	92.7	165.3	240.1
4	103.7	173.5	244.1

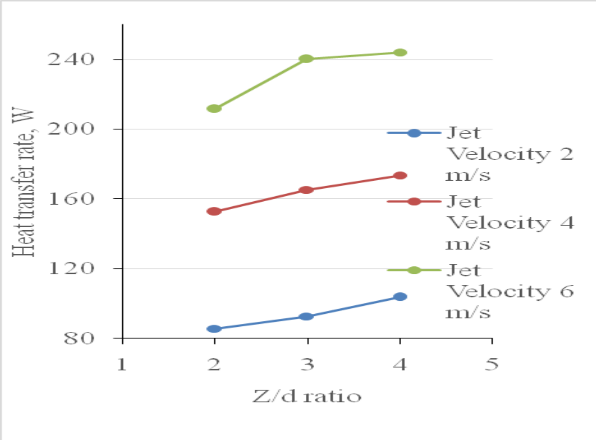

Fig. 5.6Heat transfer rate comparisons for the Variant-5 Heat Sink

VI. CONCLUSION

The investigation for this impingement cooling project was carried out entirely through numerical simulations. In all cases, the CFD results were analysed to evaluate the heat transfer performance and flow characteristics of the system.
The heat transfer rate for the Base Model heat sink had increased by 73% when the jet impingement velocity had been increased from 2 m/s to 4 m/s for the Z/d = 2.

This highlights the influence of jet impingement velocity over the heat removal mechanisms.

When the jet impingement velocity was increased to 4 m/s, the heat transfer enhancement for the pin-finned heat sink was as much as 26% in comparison to the Base Model.

In general, heat transfer enhancement for the pin-finned heat sink was significantly higher than the plate-finned heats under the identical impingement cooling process.

All the pin-finned heat resulted in heat transfer enhancement while the plate-finned heat sink had lower performance than the Base Model.

The performance of pin-finned heat sinks (Variant-3, Variant-4 and Variant-5) had near identical heat transfer characteristics for the Z/d = 3 and Z/d = 4 for the jet velocity of 6 m/s.

However, Variant-4 had high heat transfer rate among all cases for the Z/d = 2. Hence, this model should be preferred in case the design requirements demand a lower jet impingement positioning.

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