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Heat transfer of a tapered fin heat sink under natural convection

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ABSTRACT

Extended surface plays a major role in heat transfer for several heat generating devices the waste heat is dissipated to ambient by heat sink in electronic components and fins in internal combustion engines, in present study 3 configurations of tapered fin heat sink is proposed with 9 cases of heating power the computational model was created in ANSYS Fluent and analyzed with different heating power to predict heat transfer characteristics of tapered fin heat sink with taper angle of 1°, 2°and 3°with heating power of 5, 10, 20, 30, 40, 50, 60, 70 W, the 2° tapered fin heat sink exhibits maximum heat transfer coefficient with low thermal resistance compared to other configurations of tapered fin heat sinks ($TFHS_s$) under natural convection condition.

Selection and peer-review under responsibility of the scientific committee of the 3rd International Conference on Materials, Manufacturing and Modelling.

1. Introduction

Heat concentration is a major issue in electronic components the dissipation of heat is a challenging part in heat transfer from internal combustion engines as well as the devices where heat generation takes place, the heat sink is a extended surface which is patched with heat generating devices such as processor and graphic card in computers, the heat sink consists of fins these fins when attached with internal combustion engine cylinder it is termed as internal combustion engine fins. Fins have higher capable in increasing heat dissipation due to their nature of extended surface, the various parameters i.e. fin height, fin width, fin spacing and fin length influences the parameter and effectiveness and efficiency of heat sink. To enhance the thermal performance of heat sink fin spacing is optimized with different taper angle this determines the optimal temperature distribution with fin spacing enhances maximum heat transfer in natural convection condition [1]. Further heat sink with different orientation in natural convection was predicted that heat transfer area with blockage in convection that deteriorates the heat dissipation in rectangular fin heat sinks [2]. Analyzed heat transfer performance of aluminium fin heat sink with different impingement distance with fixed pumping power that shows high thermal performance compared to pin fin heat sink [3]. The concentric ring in radial heat sink was used to predict thermal performance [4]. Heat transfer rate is increased by placing solid aluminium cylinder in heat sink wall of metal foam with determining the effect of nusselt number [5]. Natural convection analysis was performed in radial heat sink with perforated ring by optimizing orientation angle, perforation hole diameter with length of perforation to increase its heat transfer [6]. Density based topology optimization is considered for three dimensional heat sink in natural convection by optimizing fin length and thickness ratio [7]. Investigated the heat transfer characteristic under inclined condition of heat sink base with and without metal foam [8]. Predicted thermal performance with dual fin heat sink by optimizing fin height and fin spacing [9]. To increase the thermal performance of heat sink open slot design in metal foam was proposed [10]. The shape dependent effect is investigated in natural convection considering topology optimization method for thermal enhancement in heat sinks [11]. Further the staggered array of hollow pin fins nexus with radially-placed plate fins structured as a hollow hybrid fin heat sink to improve thermal performance [12]. An asymptotic method is developed for radial heat sink to enhance the heat transfer coefficient with a new correlation considering analytical and experimental methods [13]. The experimentation was conducted in plate fin heat sink and plate cubic fins heat sink under natural convection to analyze thermal performance [14]. A shape dependent convection model was proposed by opting the method of three dimensional topology optimization for improvement in thermal resistance and thermal performance of radial plate fin heat sink [15]. Perpendicularly arranged short fins was arranged to enhance natural convective

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Nomenclature

Tave	the average temperatures of the heat plate	k	air thermal conductivity
Tsur	ambient temperature	Cp	air specific heat capacity
Qhs	heat dissipation power	μ	air viscosity
A	heat sink surface area	ρ	air density at temperature T
ΔT	temperature difference between the heat sink surface and ambient	ρ_0	air density at T_0
ρ	air density	β	air thermal expansion coefficient
u, v, w	components of velocity	ρ	Density of work piece
x, y, z	components of coordinate	T_0	Ambient temperature
T	air temperature	q	heat flux

heat transfer [16]. Pin fin hybrid metal foam heat sink was proposed for thermal management with enhancement in hydraulic performance [17]. To achieve the steady temperature internal cavity in tapered pin array was designed to enhance the thermal performance [18]. The pin fin was proposed in aluminum foam heat sink to improve fluid flow and thermal performance [19]. Further a novel displacement amidst fin array was employed in plate fin heat sink under natural convection condition for heat transfer enhancement [20]. Multi objective optimization is considered for finned and non – finned metal foam heat sink to analyze thermal performance [21]. Heat transfer coefficient and thermal resistance was analyzed with different mounting angle of plate fin heat sink in which 90 degree mounting angle exhibits higher thermal performance [22]. Plate pin fin is used with different pin configuration under forced convection condition to predict thermal resistance and profit factor [23]. The objective of this study is to propose the plate fin heat sink design to enhance maximum heat transfer with decrease in thermal resistance, Hence tapered fin configuration was proposed to predict thermal performance of plate fin heat sink, Further forced convection could be analyzed to predict profit factor, nusselt number and thermal hydraulic performance.

2. Tapered fin heat sink

Tapered fin heat sink (TFHS) consist of plate fin heat sink with inline arrangement, the fins are tapered from base with different taper angle the configuration parameters are shown in Fig. 1 and tabulated in Table 1, L represents the length of fin, w is the width of the fin, H is the height of fin, θ is the taper angle of tapered fin. The heat sink base size is 150 mm × 76 mm × 5 mm, the selected material for tapered fin heat sink is aluminium 6063.

3. Physical description

The 3 – dimensional computational domain was developed under natural convection condition, the heating power at the base of heat sink was applied with convection in walls, also creating environment for heat transfer in computational model for prediction of heat transfer in tapered fin heat sink (TFHS), the modeling involves some simplifying assumptions to reduce computational resources are as follows [22]:

1) The air flow is treated as a three-dimensional steady laminar flow.
2) Boussinesq model is used in air zone.
3) The temperature and heat flow of the heat plate are even.
4) Except density, the properties of air are constant.
5) Air is nonslip on the fin surface.
6) The viscous dissipation and radiation heat transfer are not considered.

4. Numerical modeling

4.1. CFD model

Computational fluid dynamic (CFD) analysis has been rigorously conducted for 9 cases, which are 3 configurations shown in Table 1 at different heating power range between 5 W and 80 W to obtain generous range of thermal resistance and heat transfer coefficient. ANSYS CFD (FLUENT) were used for mesh generation the flow is assumed to be steady and incompressible flow and boussinesq approximation for the density model. The milestone of the numerical analysis is to generate purely convection heat transfer data

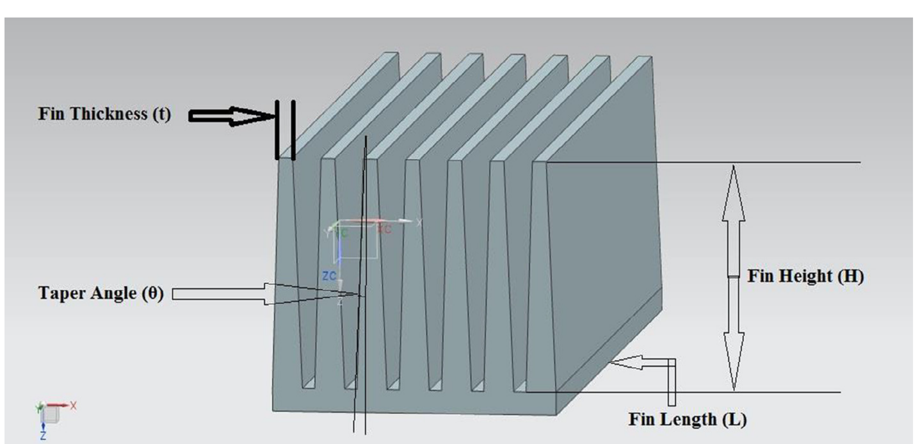


Fig. 1. The structure of a tapered fin heat sink (TFHS).

Table 1
Dimensions of Tapered Fin Heat Sink (TFHS).

Fin Length (L)	Fin Height (H)	Fin Thickness (t)	Fin Width (w)	Number of fins	Taper angle(θ)
150 mm	50 mm	5 mm	76 mm	7	1°, 2°, 3°

Table 2
Numerical simulation conditions.

Physical conditions	
Fluid	Steady and incompressible air
Heat sink material	Aluminum 6063
Boundary condition and thermal conditions [22]	
Air temperature	25 °C
Inlet Pressure	1 atm
Outlet Pressure	1 atm
Heat sink base heating power [W]	5, 10, 20, 30, 40, 50, 60, 70, 80
Solution models	
Viscous model	K – ε turbulent model
Solver type	Pressure based
Pressure-velocity coupling	SIMPLE
Density model	Boussinesq approximation

around the TFHS, and thus thermal radiation was neglected, the details were demonstrated in (Table 2).

Governing equations for the computations are shown in Eqs. (1)–(9) [22] as follows.

Thermal resistance Rth can be calculated by following equation

$$R_{th} = \frac{T_{ave} T_{sur}}{Q_{hs}} \tag{1}$$

Heat transfer coefficient h of the heat sink can be calculated from the following

$$h = \frac{Q_{hs}}{A.\Delta T} \tag{2}$$

4.2. Model for fluid region

$$\frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0 \tag{3}$$

Energy equation is obtained on the basis of energy balance characteristics

$$\frac{\partial(\rho uT)}{\partial x} + \frac{\partial(\rho vT)}{\partial y} + \frac{\partial(\rho wT)}{\partial z} = \frac{\kappa}{c_p}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) \tag{4}$$

The natural-convection flow is driven by the air density change and gravity force under heating condition. For external natural convection flow, the momentum equations can be written as:

$$\frac{\partial(\rho u^2)}{\partial x} + \frac{\partial(\rho uv)}{\partial y} + \frac{\partial(\rho uw)}{\partial z} = -\frac{\partial P}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) \tag{5}$$

$$\frac{\partial(\rho uv)}{\partial x} + \frac{\partial(\rho v^2)}{\partial y} + \frac{\partial(\rho uw)}{\partial z} = -\frac{\partial P}{\partial y} + \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right) + g(\rho - \rho_0) \tag{6}$$

$$\frac{\partial(\rho uw)}{\partial x} + \frac{\partial(\rho vw)}{\partial y} + \frac{\partial(\rho w^2)}{\partial z} = -\frac{\partial P}{\partial z} + \mu\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right) \tag{7}$$

4.3. Model for solid region

There is no internal heat source in the heat sink, so energy equation of solid region can be written as:

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = 0 \tag{8}$$

For natural-convection flow, the simulation can get quick convergence with the Boussinesq model

$$\rho - \rho_0[1 - \beta(T - T_0)] \tag{9}$$

5. Simulated study of tapered fin heat sink

5.1. Heat transfer coefficient

To evaluate heat transfer coefficient temperature difference is obtained with heat flux from CFD fluent and formulated using Eq. (2), the results obtained from numerical simulation validates the straight fin model (Normal heat sink model) referenced in [22], below Table 3 and Fig. 2 demonstrates the values of heat transfer coefficient with different heating power, contour plots of heat transfer coefficient and temperature distribution obtained from CFD Post is represented in Figs. 3–5.

Table 3
Representation of heat transfer coefficient obtained from numerical simulation for aluminium 6063.

Heating power [W]	Heat transfer coefficients (W/m^{2}K) - Normal heat sink [22]	Heat transfer coefficients (W/m^{2}K) for 1° degree tapered fin heat sink	Heat transfer coefficients (W/m^{2}K) for 2° degree tapered fin heat sink	Heat transfer coefficients (W/m^{2}K) for 3° degree tapered fin heat sink
5	3.98	4.16	5.38	2.03
10	5.78	5.98	6.77	2.39
20	6.33	6.57	7.65	2.96
30	7.66	8.10	9.73	3.22
40	8.78	8.98	10.03	4.00
50	9.37	9.48	10.67	4.58
60	9.98	10.02	11.03	5.08
70	10.86	10.57	11.68	5.96
80	12.58	11.38	12.96	6.98

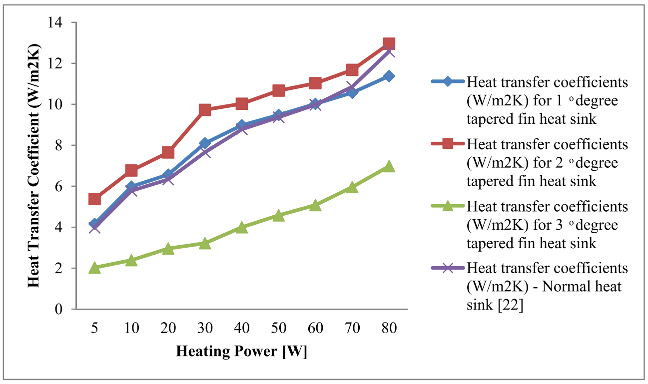


Fig. 2. Comparison of heat transfer coefficient with different heating power and configuration for aluminium 6063.

6. Simulated study of thermal resistance for tapered fin heat sink (TFHS)

The average temperature and surface temperature obtained with heat transfer coefficient obtained from CFD analysis for aluminum 6063 is calculated considering Eq. (1), the results of thermal resistance is tabulated in Table 4 and shown in Fig. 5 the result obtained validates the straight fin (Normal heat sink model) referenced in [22] the results of thermal resistance were compared in Fig. 6.

7. Conclusion

Heat transfer characteristics of tapered fin heat sink are investigated under natural convection condition with different taper fin angles, the result shows convergence with experimental data of heat transfer coefficient and thermal resistance of published research referenced in [22], the following observations are withdrawn from present analysis.

1. Heat transfer coefficient for 2° tapered fin heat sink is 11.03 W/m^{2}K at 60 W of heating power and 12.96 W/m^{2}K at 80 W of heating power, this shows the maximum heat transfer observed in 2° tapered fin heat sink configuration.
2. Heat transfer coefficient for normal straight fin heat sink and 2° tapered fin heat sink shows an error of 2.93% at 80 W of heating power which validates the present analysis.
3. Thermal resistance for 2° tapered fin heat sink at 80 W is 0.6 K/W which is minimum from compared to other configurations of tapered fin heat sink.
4. Thermal resistance is maximum for 3° tapered fin heat sink with minimum heat transfer coefficient is due to stagnation at the fin origin which concentrates the temperature at the base of fin.

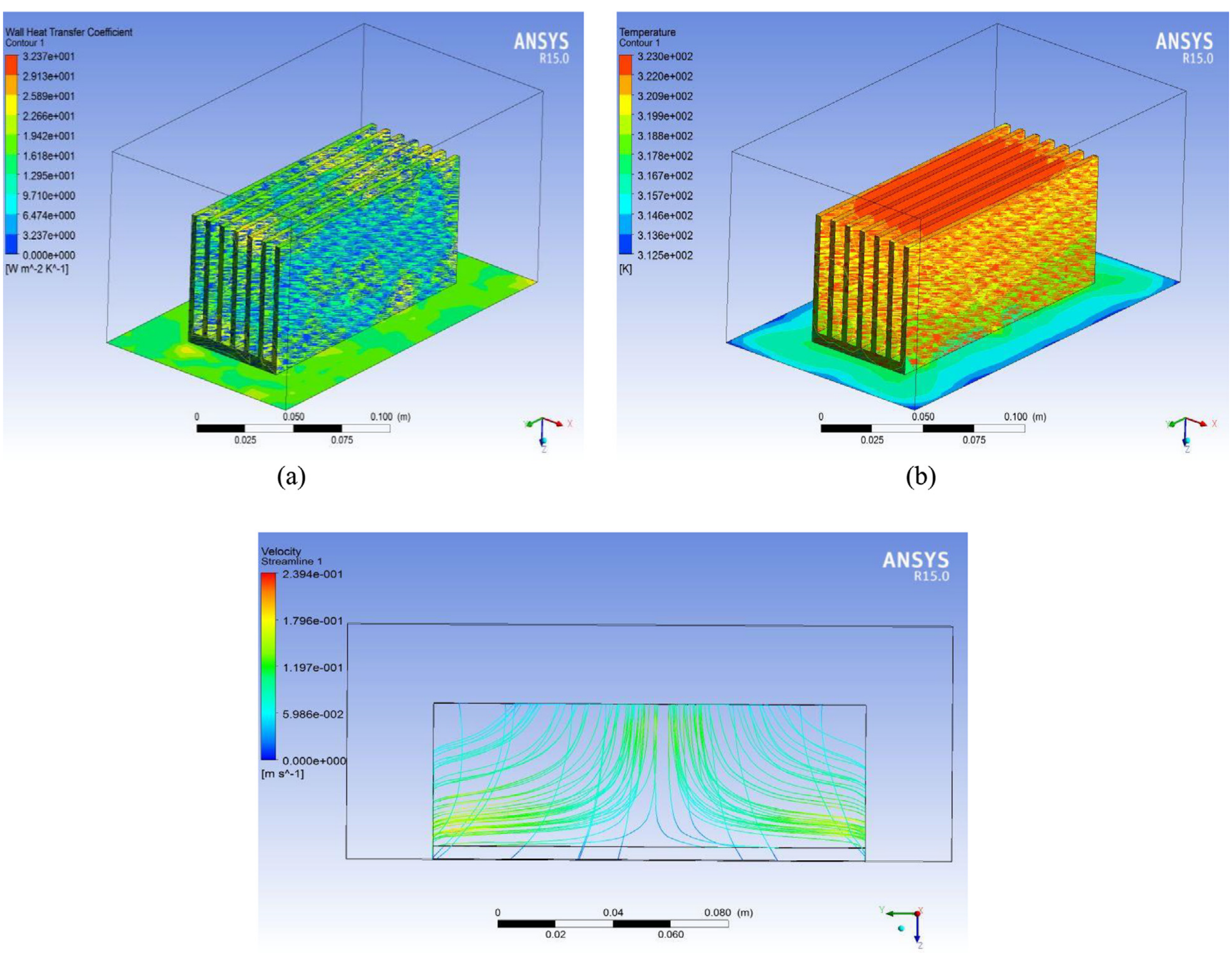
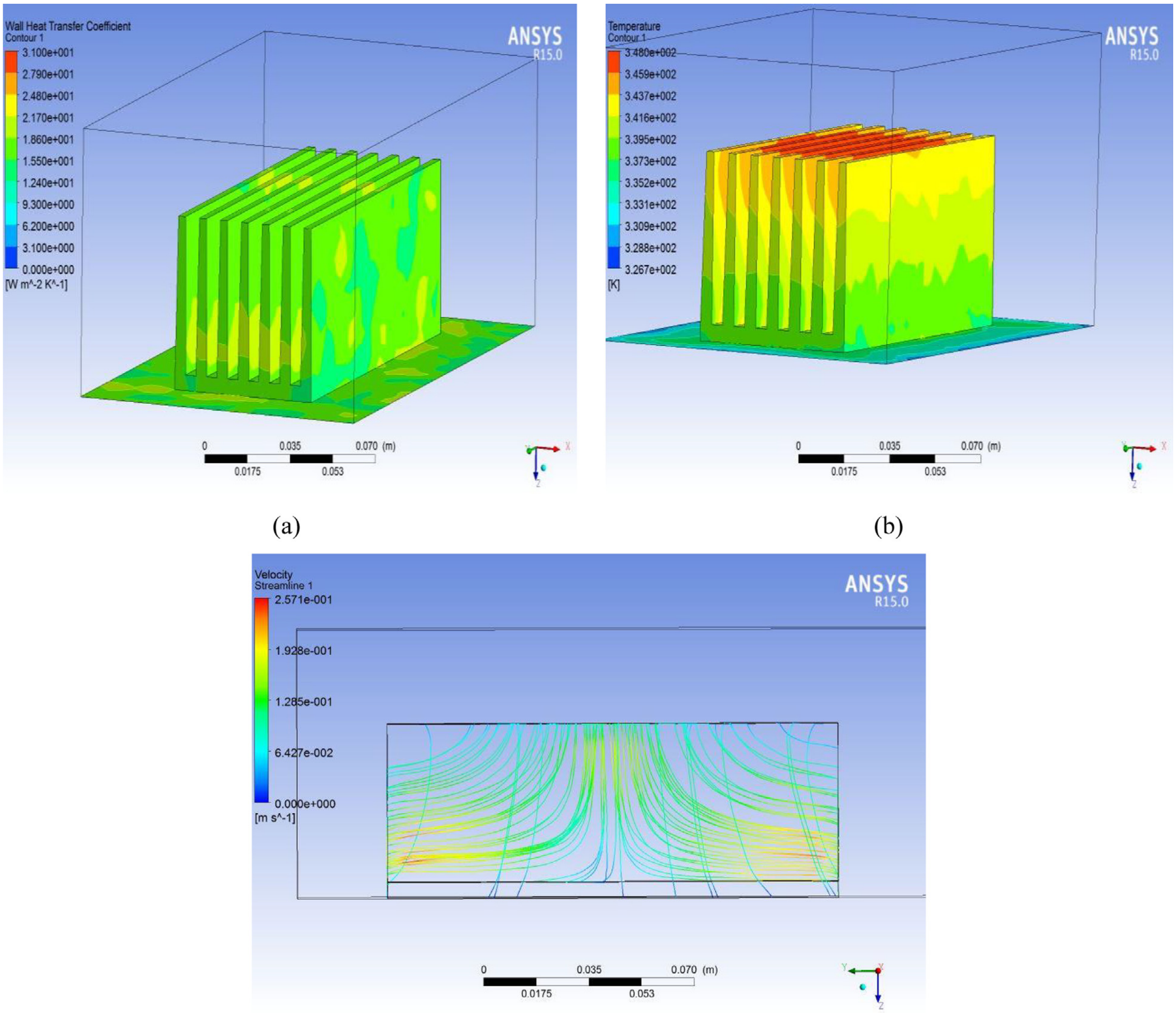


Fig. 3. (a) Heat transfer coefficient of straight fin heat sink (Normal heat sink), (b) Temperature, (c) Velocity streamline.



(c)

Fig. 4. (a) Heat transfer coefficient of 1° tapered fin heat sink, (b) Temperature, (c) Velocity streamline.

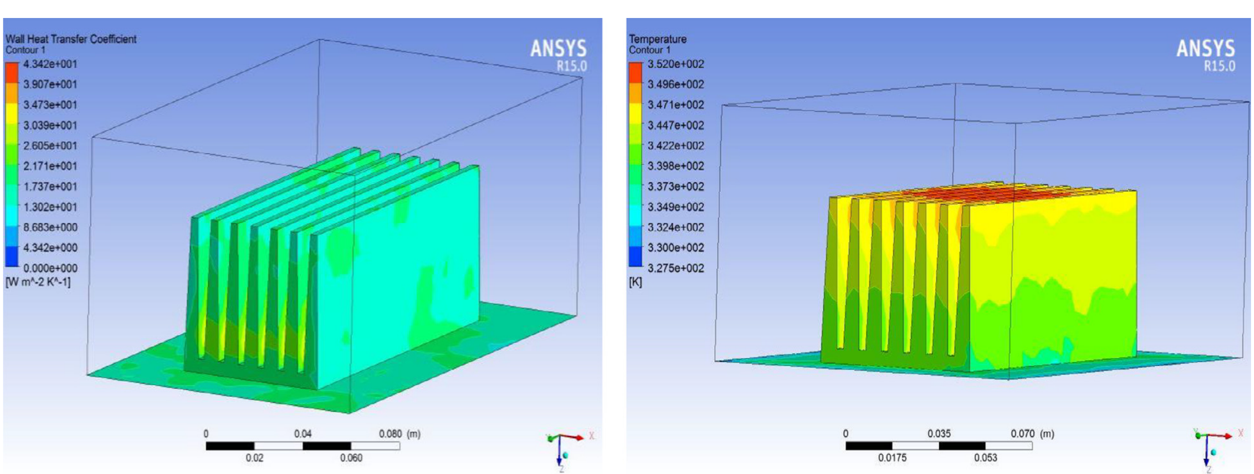


Fig. 5. (a) Heat transfer coefficient of 2° tapered fin heat sink, (b) Temperature.

Table 4
Representation of thermal resistance obtained from numerical simulation for aluminium 6063.

Heating Power [W]	Thermal Resistance for normal heat sink [22]	Thermal Resistance for 1° tapered fin heat sink	Thermal Resistance for 2° tapered fin heat sink	Thermal Resistance for 3° tapered fin heat sink
5	2.3	2.2	1.8	2.8
10	2.1	2.0	1.6	2.6
20	1.9	1.8	1.5	2.3
30	1.8	1.6	1.4	2.2
40	1.7	1.5	1.3	2.1
50	1.6	1.4	1.2	1.8
60	1.5	1.3	0.9	1.6
70	1.3	1.2	0.8	1.5
80	1.2	1.0	0.6	1.3

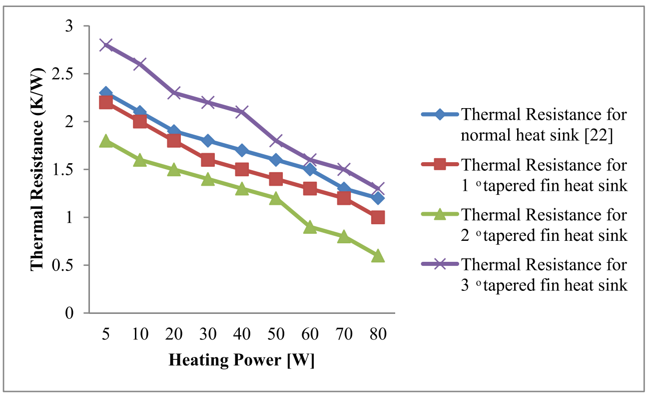


Fig. 6. Comparison of thermal resistance with different heating power and configuration for aluminium 6063.

CRediT authorship contribution statement

Anil Kumar Rao: Software, Investigation, Validation. **Vandana Somkuwar:** Conceptualization, Methodology, Validation, Formal analysis.

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.

References

[1] Kyu Hyung Do et al., General correlation of a natural convective heat sink with plate-fins for high concentrating photovoltaic module cooling, Solar Energy 86 (2012) 2725–2734.
[2] Q. Shen et al., Orientation effects on natural convection heat dissipation of rectangular fin heat sinks mounted on LEDs, Int. J. Heat Mass Transf. 75 (2014) 462–469.
[3] C. Byon et al., Heat transfer characteristics of aluminum foam heat sinks subject to an impinging jet under fixed pumping power, Int. J. Heat Mass Transf. 84 (2015) 1056–1060.
[4] B. Li et al., Investigation of natural convection heat transfer around a radial heat sink with a concentric ring, Int. J. Heat Mass Transf. 89 (2015) 159–164.
[5] W.-H. Shih et al., Heat-transfer characteristics of aluminum-foam heat sinks with a solid aluminum core, Int. J. Heat Mass Transf. 97 (2016) 742–750.
[6] B. Li et al., Investigation of natural convection heat transfer around a radial heat sink with a perforated ring, Int. J. Heat Mass Transf. 97 (2016) 705–711.
[7] J. Alexandersen et al., Large scale three-dimensional topology optimisation of heat sinks cooled by natural convection, Int. J. Heat Mass Transf. 100 (2016) 876–891.
[8] M. Paknezhad et al., Effect of aluminum-foam heat sink on inclined hot surface temperature in the case of free convection heat transfer, Case Stud. Thermal Eng. 10 (2017) 199–206.
[9] D. Jeon et al., Thermal performance of plate fin heat sinks with dual-height fins subject to natural convection, Int. J. Heat Mass Transf. 113 (2017) 1086–1092.
[10] Shangsheng Feng et al. Natural convection in metal foam heat sinks with open slots, http://dx.doi.org/10.1016/j.expthermflusci.2017.07.010.
[11] Y. Joo et al., Topology optimization of heat sinks in natural convection consideringthe effect of shape-dependent heat transfer coefficient, Int. J. Heat Mass Transf. 109 (2017) 123–133.
[12] Nico Setiawan Effendi et al. Prediction methods for natural convection around hollow hybrid fin heat sinks, Int. J. Thermal Sci. 126 (2018) 272–280.
[13] H. Kwon et al., Analytic approach to thermal optimization of horizontally oriented radial plate-fin heat sinks in natural convection, Energy Convers. Manage. 156 (2018) 555–567.
[14] S. Sadrabadi Haghighi et al., Natural convection heat transfer enhancement in new designs of plate-fin based heat sinks, Int. J. Heat Mass Transf. 125 (2018) 640–647.
[15] Y. Joo et al., Efficient three-dimensional topology optimization of heat sinks in natural convection using the shape-dependent convection model, Int. J. Heat Mass Transf. 127 (2018) 32–40.
[16] Shangsheng Fenget al., Natural Convection in a Cross-Fin Heat Sink, https://doi.org/10.1016/j.applthermaleng.2017.12.049.
[17] Yongtong Liet al., Hydraulic and Thermal Performances of Metal Foam and Pin Fin Hybrid Heat Sink, https://doi.org/10.1016/j.applthermaleng.2019.114665.
[18] M. Baldry et al., Optimal design of a natural convection heat sink for small thermoelectric cooling modules, Appl. Therm. Eng. 160 (2019) 114062.
[19] Y. Li et al., Enhancing the performance of aluminum foam heat sinks through integrated pin fins, Int. J. Heat Mass Transf. 151 (2020) 119376.
[20] A. Abbas et al., Augmentation of natural convection heat sink via using displacement design, Int. J. Heat Mass Transf. 154 (2020) 119757.
[21] N. Bianco et al., Multi-objective optimization of finned metal foam heat sinks: Tradeoff between heat transfer and pressure drop, Appl. Therm. Eng. 182 (2021) 116058.
[22] X. Meng et al., Natural convection heat transfers of a straight-fin heat sink, Int. J. Heat Mass Transf. 123 (2018) 561–568.
[23] Y.-T. Yang et al., Investigation of planted pin fins for heat transfer enhancement in plate fin heat sink, Microelectron. Reliab. 49 (2009) 163–169.