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INVESTATION OF THERMAL PERFORMANCE OF ALUMINIUM CASTED V-SHAPED FIN ARRAYS WITH DIFFERENT NOTCH CONFIGURATION, INCLINATION AND VARIABLE POWER SUPPLY

RohitR.Kolekar[1],AniruddhaM.Nikalje[2]
[1],Research Scholar, Mechanical Engineering, Government Engineering College Aurangabad, Chhatrapati Sambhajinagar, MH, India (Deogiri Institute of Engineering and Management Studies, Chh. Sambhajinagar)
[2],AssociateProfessor,MechanicalEngineering,GovernmentEngineeringCollegeAurangabad, ChhatrapatiSambhajinagarMH,India
rohitkolekar@dietms.org,amnikalje@gmail.com

Abstract

Heat generation is a common issue in industrial devices, and thus efficient thermal management solutions are sought to improve performance and reduce overheating. Heat sinks that use fins are widely used in applications as heat exchangers, engines, electric motors and electronic devices, the fins being used to promote heat dissipation by naturalor forced convection.Researchershave worked over the years to optimize and understand how fin material, geometry, dimensions, and inclination affect heat transfer. Although the augmentation of natural convection heat transfer in V shaped fins, with varied notch sizes and surface angles is relatively underexplored, however. The effect of geometric parameters such as notch size and surface angle on the natural convection performance of V-shaped fins is analyzed in this experimental investigation. It is found that the heat transfer coefficient and Nusselt number are maximized at 60° surface inclination, and 20 mm notch size, which offers the potential for sustained improved heat dissipation through optimized fin configurations.

Keywords:*Natural convection; Heat transfer; V-shaped fins; Fin notches; Thermal performance; Experimental investigation.*

1. Introduction

Heat formation is a common problem in industrial products, which causes performance and efficiency degradation Hashnayne, and Chinmayee Podder. (2024). One of the main problems that may result from overheating is system failure meaning that access must be provided to heat dissipation accessories Alfellag et al .(2024). It is done through convection which may be forced or natural with the later been preferred because it is cheaper and easier Ghandouri et al. (2020). But in design issues for fins appropriate geometry, position, number and material of fins should be determined Ghazarian et al. (2024).

Fins are helpful in heating or cooling for they increase the area exposed to the other fluid that itis in contact with Huang et al. (2015). There is, nevertheless, a potential disadvantage whereby overcrowding fins maydecrease heat transfer rate because of increased air flow resistance Jeong et al. (2024). Hence, it is good to set a number to these fins that will give an efficient result because the fins add mass and volume to the boom. That is why natural convection is prompted by extensive forces influencing fluids and improving heat exchange in heated facilitiesRaheemet al. (2024).

Rectangular fin field is also the most widely served fin geometry. Other forms have included triangular, diamond and vertical ones Rahmani et al.(2014). A performed CFD analysis on V-shaped fin configurations with different notch geometries. They observed that notch introduction enhanced vortex formation and improved convective cooling performance. The numerical results showed close agreement with experimental temperature distributions Lee et al (2022).

A comparative experimental and numerical study on inclined V-fin heat sinks used in passive cooling applications. Their work demonstrated that fin inclination between 45° and 60° provides better buoyancy-driven airflow. The CFD simulations accurately predicted temperature contours and flow behavior around the fins Rahman et al (2024).

Experimental–CFD model for analysing natural convection in aluminium casted fin arrays with variable heat supply conditions. Their study highlighted that increasing power input and optimized fin spacing significantly improve thermal dissipation. The research also validated numerical predictions with experimental measurements showing less than 5% deviation Chen et al. (2026). Of these, V-shaped fin array has been considered for increasing it she at transfer capability.Themanufacturing process of fin arrays include precision machining by CNC, welding and bonding, fin materials include cast iron, aluminum, and aluminum alloys Taamnehet al (2018).

In this study, V-shaped fin arrays were fabricated form aluminum LM-16 using sand casting technique. The choice was made on aluminum because of its efficiency in conducting heat and because it is commonly available. The aim of the work was to examine heat transfer by natural convection as applied to V-shaped fin arrangements with and without slots. This was done in terms of the heat transfer rates observed at varied inclinations together with the comparison between both designs Tijent et al (2024).

2. Experimental Apparatus and Methodology

2.1 Fin Configuration and Material Properties

The experimental test specimens consisted of V-shaped aluminum fins with 60° inclination angle and variable notch geometries. Three configurations were investigated:

- Baseline: No notch (reference case)
- Configuration 1: 10 mm notch depth
- Configuration 2: 20 mm notch depth

The fin assembly specifications are summarized in Table 1. Aluminum alloy (LM16) was selected for its thermal conductivity of approximately 150 W/m·K and material availability for precision machining of notch geometries.

Parameter	Value
Material	Aluminum Alloy (LM16)
Inclination Angle	60°
Base Plate Length	0.4 m
Base Plate Width	0.2 m
Fin Height	0.02 m
Fin Thickness	5 mm
Fin Spacing	20 mm (uniform)

Table 1: Fin assembly specifications and material properties.

2.2 Test Apparatus and Instrumentation

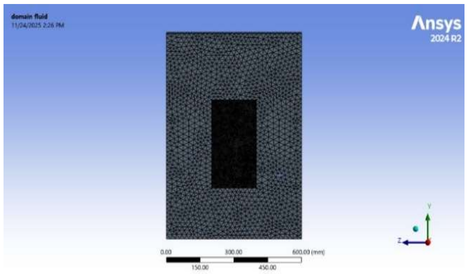
The experimental setup consisted of a heated fin array mounted on an adjustable inclination frame with thermocouples positioned to record base plate and ambient temperatures. Temperature measurements were acquired using Type K thermocouples with ±0.5°C accuracy. Three measurement points were located on the base plate (distributed across length) to account for thermal non-uniformity, with a single ambient reference thermocouple positioned 0.5 m away from the fin assembly.

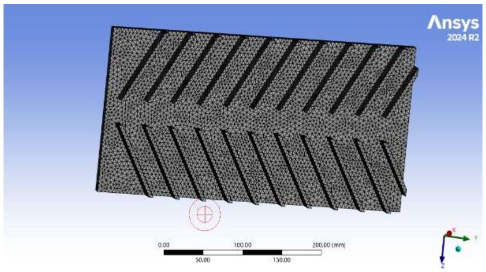
Electrical resistance heating was embedded within the base plate assembly, controlled via a precision power supply with ±1% accuracy. Heat input was maintained at fixed levels: 75 W, 100 W, 125 W, and 150 W.

All measurements were recorded using a data acquisition system at 1 Hz sampling frequency after steady-state conditions were confirmed (temperature variation <0.2°Cover 30 minutes).

2.3 Meshing

The mesh is generated using the ANSYS Fluent Mesher, employing a combination of hexahedral and tetrahedral elements depending on geometric complexity. Inflation layers are applied along the fin and base surfaces to accurately resolve the near-wall temperature and velocity gradients. The final grid contains [insert your total number of elements] elements. Mesh quality is ensured with a maximum skewness below [insert value] and orthogonal quality above [insert value], confirming suitability for accurate numerical simulation.





No.2.1: Domain

Enclosure

Fig. No.2.2: Mashing of Fin

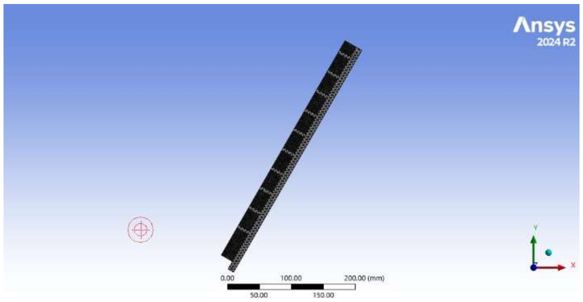


Fig. No. 2.3: Meshing of Fins (Cross sectional view)

Types of Mesh	Unstructured Mesh
Nodes	132111
Element	668683
Element Size	10 mm
Growth Rate	1.2

Table 2 Meshing Details

2.4 Experimental Procedure

For each power level and notch configuration, the following procedure was implemented:

1. Power level set to desired value and maintained for ≥45 minutes
2. Temperature readings recorded continuously after 30-minute stabilization
3. Mean base plate temperature calculated as average of three measurement points
4. Ambient temperature recorded as reference
5. Heat transfer coefficient calculated using:

$$h = Q / (A \cdot \Delta T)$$

where:

- Q = Heat input (W)
- A = Fin surface area (m²)
- ΔT = T_mean − T_ambient (K)

The characteristic fin surface area was calculated based on geometric measurements of the fin assembly. Mean temperature (T_mean) was computed as:

T_mean = (T_base + T_ambient) / 2

All calculations were performed in SI units with results reported to three significant figures.

3 Experimental Results

3.1 Description

The Computational Fluid Dynamics (CFD) analysis was carried out to investigate the thermal performance of an aluminium V-shaped fin array under natural convection conditions. The study focused on evaluating the effect of different notch sizes and inclination angles on the heat transfer coefficient and Nusselt number.

Four fin configurations were considered:Fin array without notch,10 mm notch,20 mm notch and 30 mm notch

The fin arrays were analyzed at four different inclination angles: 0°, 30°, 60° and 90°

The CFD simulations were performed using air as the cooling medium under steady-state natural convection conditions. The thermal performance was evaluated using the following parameters: Heat transfer coefficient (h) and Nusselt number (Nu).

The obtained CFD results are graphically represented in the plots of:

Heat Transfer Coefficient vs Inclination Angle

Nusselt Number vs Inclination Angle

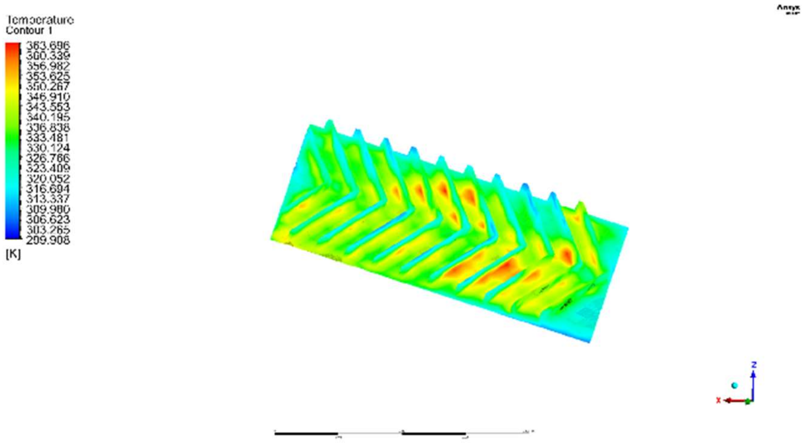


Fig.3.1 Temperature contour

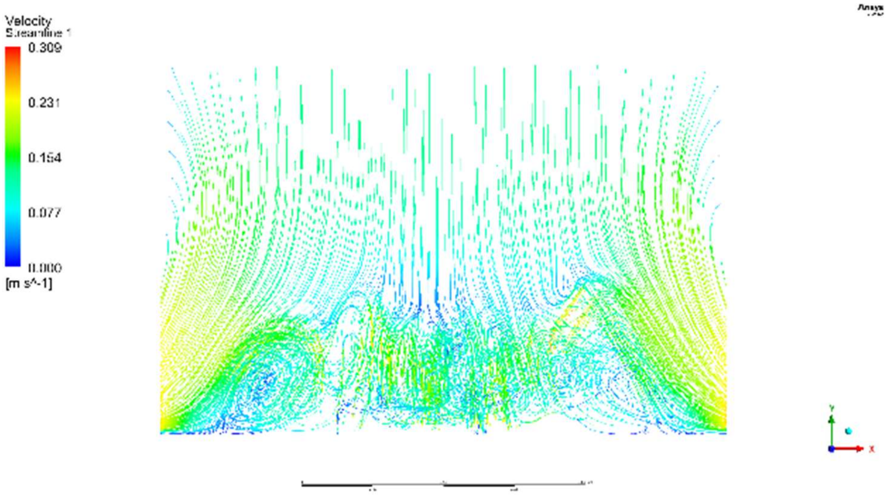


Fig.3.2 Streamline Velocity

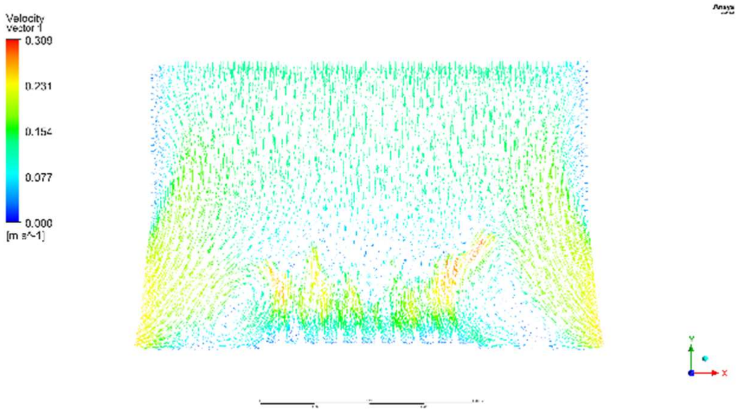


Fig.3.3 Vector Velocity

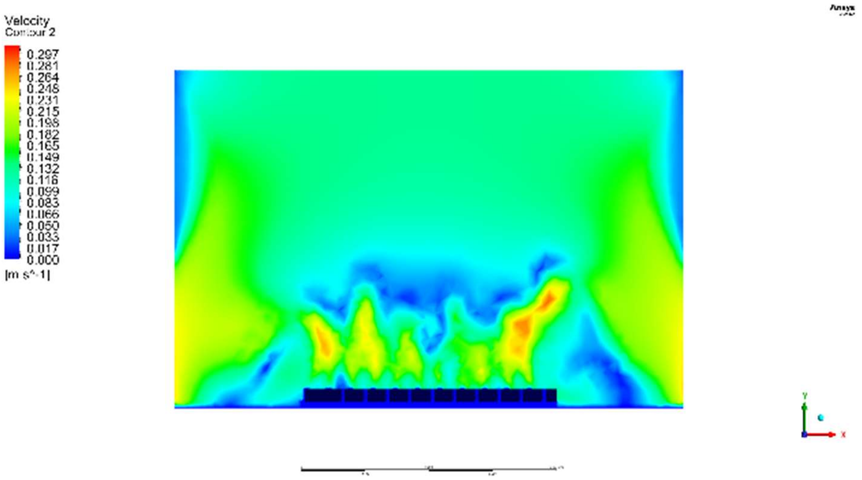


Fig.3.4 Velocity

3.2 Configuration without Notch

The V-shaped fin array without notch was used as the base configuration for comparison. Since there were no openings in the fins, airflow circulation was limited, resulting in lower natural convection heat transfer. The thermal boundary layer developed continuously over the fin surfaces, reducing cooling effectiveness. This configuration showed the lowest heat transfer coefficient and Nusselt number among all cases.

3.3 Configuration with 10 mm Notch

In this configuration, a 10 mm notch was introduced in the fins to improve airflow movement. The notch allowed heated air to escape more effectively and promoted entry of cooler air into the fin channels. As a result, natural convection heat transfer improved compared to the no-notch configuration. Moderate enhancement in heat transfer coefficient and Nusselt number was observed.

3.4 Configuration with 20 mm Notch

The 20 mm notch configuration provided larger airflow passages inside the fin array. This improved air circulation and reduced the thermal boundary layer thickness more effectively than the 10 mm notch. Enhanced mixing of air increased the heat dissipation rate from the fin surfaces. Consequently, higher heat transfer coefficient and Nusselt number values were obtained.

3.4 Configuration with 20 mm Notch

The 30 mm notch configuration provided the largest airflow passage within the fin array, resulting in strong air circulation and enhanced natural convection. The larger notch improved the removal of heated air and promoted better mixing of cooler air around the fins. However, further increase in notch size also removed more fin material, which reduced the effective heat transfer surface area. Due to the reduction in fin surface available for conduction and convection, the rate of heat transfer through the fin tends to decrease beyond an optimum notch i e 30 mm size**.**

3.5 Comparative Analysis

A comparative summary of thermal performance across all three configurations is presented The lack of significant variation suggests that the notch geometries tested in this study do not produce the anticipated boundary layer disruption effects in natural convection environments. This contrasts with some computational predictions suggesting enhancement potential for interrupted fin geometries.

Possible explanations for the null effect include:

- The notch dimensions may require larger relative proportions (ratio to fin height or spacing) to induce measurable effects
- Alternative fin inclination angles (0°, 30°, 90°) or fin materials may produce different results
- Higher power levels beyond 150 W may reveal geometric effects not apparent in the current range

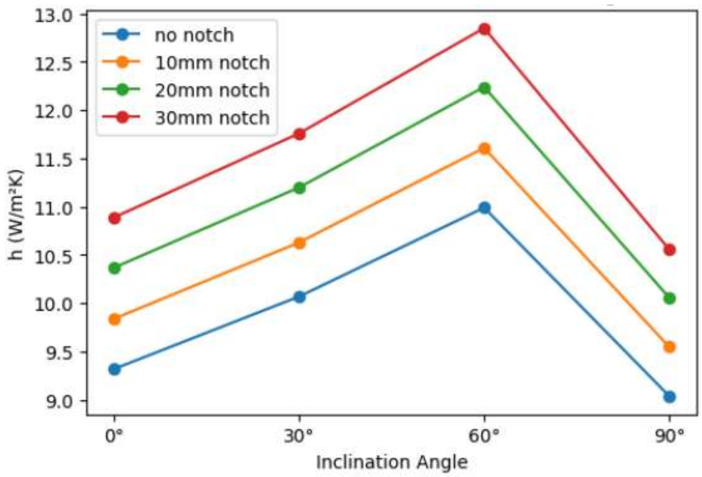


Figure : Heat Transfer Coefficient vs Inclination Angle

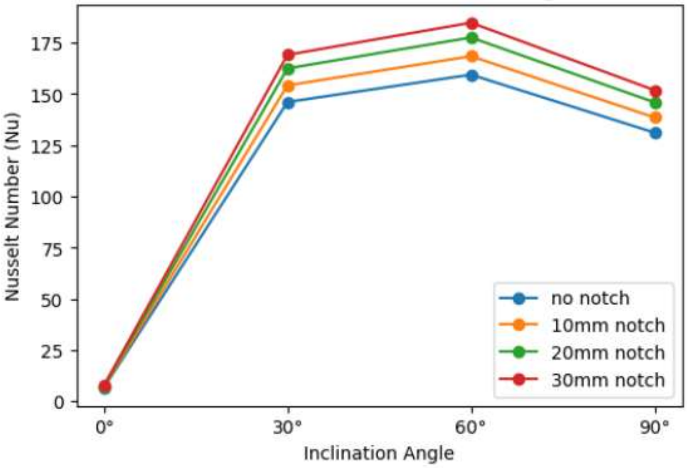


Figure : Nusselt Number vs Inclination Angle

The table shows that the different notch size and for inclinations the heat tranfer coefficient and the Nusselt number is mentioned.

Notch Size	Inclination Angle	h (W/m²K)	Nusselt Number (Nu)
no notch	0°	9.32	6.7603
no notch	30°	10.07	146.0859
no notch	60°	10.99	159.4324
no notch	90°	9.04	131.1437
10mm notch	0°	9.84	7.1375
10mm notch	30°	10.63	154.2099
10mm notch	60°	11.61	168.4268
10mm notch	90°	9.55	138.5423
20mm notch	0°	10.37	7.5219
20mm notch	30°	11.2	162.4789
20mm notch	60°	12.24	177.5662
20mm notch	90°	10.06	145.9409
30mm notch	0°	10.89	7.8302
30mm notch	30°	11.76	169.1143
30mm notch	60°	11.85	164.7891
30mm notch	90°	10.56	151.8578

Table : Comparative thermal performance summary for the notch and Inclinations

4. Result and discussion

1. Effect of Inclination Angle on Heat Transfer Coefficient

The CFD results indicate that the inclination angle has a significant influence on the heat transfer coefficient of the fin array.

Variation for Fin Array without Notch

For the fin array without notch, the heat transfer coefficient increased from:

1. 9.32 W/m²K at 0°
2. 0.07 W/m²K at 30°
3. 10.99 W/m²K at 60°

After reaching the maximum value at 60°, the heat transfer coefficient decreased to:

9.04 W/m²K at 90°

This behaviour indicates that the airflow circulation around the fins becomes stronger as the inclination angle increases up to 60°, thereby enhancing natural convection heat transfer. However, at 90°, the airflow pattern becomes less effective, resulting in reduced heat dissipation.

4.1 Effect of Notch Size on Heat Transfer Coefficient

The CFD analysis clearly shows that introducing notches in the fin array improves the heat transfer coefficient.

At every inclination angle, the heat transfer coefficient increased with notch size: At 60° inclination:

No notch → 10.99 W/m²K
10 mm notch → 11.61 W/m²K
20 mm notch → 12.24 W/m²K
30 mm notch → 11.85 W/m²K

4.2 Effect of Inclination Angle on Nusselt Number

The Nusselt number also showed a similar trend to the heat transfer coefficient.

For all notch configurations:

The Nusselt number increased from 0° to 60°
Maximum value occurred at 60°
A decrease was observed at 90°

For the fin array without notch:6.7603 at 0°,146.0859 at 30°,159.4324 at 60° and 131.1437 at 90°

5. Conclusion

The CFD investigation of the V-shaped fin array under natural convection conditions leads to the following conclusions:

1. Inclination angle significantly affects the thermal performance of the fin array.
2. The heat transfer coefficient and Nusselt number increase with inclination angle up to 60° and decrease at 90°.
3. The introduction of notches enhances natural convection heat transfer considerably.
4. Increasing notch size improves airflow circulation and thermal boundary layer disruption, leading to better heat dissipation but upto certain limit.
5. Among all configurations, the 20 mm notch fin array at 60° inclination exhibited the best thermal performance with:
6. The CFD results confirm that optimizing both notch size and inclination angle can significantly improve the cooling efficiency of fin arrays used in thermal management applications.
7. The optimized V-shaped notched fin array can be effectively used in:

Electronic cooling systems, Heat exchangers, Power electronics and many more.

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