JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

"Heat Transfer Analysis of Semi-elliptical Notched Rectangular Fin Array with and without Area Compensation".

[1]Shastri Vishwambhar Naresh, [2]Mr. Jawale Pankaj V.

[1]P.G. Student, Department of Mechanical Engineering, D.I.E.M.S., Aurangabad.

[2]Assistant Professor, Department of Mechanical Engineering, D.I.E.M.S., Aurangabad.

[1]Deogiri Institute of Engineering and Management Studies, Aurangabad, Maharashtra, India.

ABSTRACT

Fins are the extended surfaces which are used to dissipate heat from hot surfaces through natural convection without any external device. Geometry and orientation of fins play a significant role in natural convection heat transfer. Fin arrays of different shapes on longitudinal and vertical surfaces are used in many of the electronic and mechanical applications to transfer heat to the surrounding so as to keep the place at the required temperature. For semi-elliptical notch fin array a chimney flow pattern is developed due to density difference. This flow pattern forms a stagnant zone near the central bottom location. That portion does not contribute much towards heat transfer. Removal of such ineffective areas from fins will reduces material cost and material weight without affecting heat transfer rate. The purpose of the present study is to investigate the performance of fin array with notch and effect on heat transfer coefficient due to compensation of notch area at various locations such as at side and at height. The dimensions of fins are changed by maintaining constant spacing between the fins. The effect on heat transfer coefficient of fin array with various geometries such as fins without notch, fins with notch, fins with compensation of notch area at sides along length and compensation of notch area at height is examined experimentally and results are compared to know better geometry of fin. The notches are given in semi-elliptical shape. The notches given are 0%, 5%, 10%, 15%, 20% to different fin arrays.

Keywords— Natural Convection, fin arrays, notches, area compensation.

1. Introduction

In the study of heat transfer, a fin is an extended surface which is used to increase the rate of heat transfer to or from the environment by increasing natural convection[1].

1.1 Convection

The effectiveness of heat transfer through convection is based largely upon the mixing movement of the fluid. With respect to the origin, types of convection are distinguished, forced and natural convection[2]. Natural or free convection is observed mainly due to the motion of the fluid due to density changes arising from the heating and cooling process[3]. The temperature gradient at the surface of the body depends on the rate at which the fluid carries the heat away[4]. Therefore, for two surfaces at temperature T1 & T2 heat transfer rate is given according to Newton's Law of cooling is,[4]

$$Q = h\,A\,(T_1 - T_2)$$

Where,

h- Heat Transfer Coefficient,

A- Area,

T_1- Temperature of Bod,

T_2-Surrounding Temperature.

1.2 Introduction to Fins:

Fins are the extended surfaces which are used for heat transfer in many electronic applications. Fins are used to enhance convective heat transfer in a wide range of engineering applications[3], and offer a practical means for achieving a large total heat transfer surface area without the use of an excessive amount of primary surface area. Natural convection heat transfer is often increased by provision of rectangular fins on horizontal or vertical surfaces in many electronic applications such as motors and transformers, in thermoelectric refrigeration systems[5]. Rectangular fins are the most popular fin type because of their low production costs and high effectiveness[6]. Natural convection heat transfer is augmented by provision of rectangular fins on horizontal or vertical surfaces in many electricaland electronic appliances[6]. In LED cooling fins are very important as they increase life span of LED[7]. Practically with electronic systems, for the thermal loading heat transfer enhancement, heat sink with fin array is often used with a typical fins arrangement and air flow direction through the channels[8]. Fins are also useful in cooling of IC engine and in hydrogen fueled vehicles[9].

Various geometries of fins-[10]

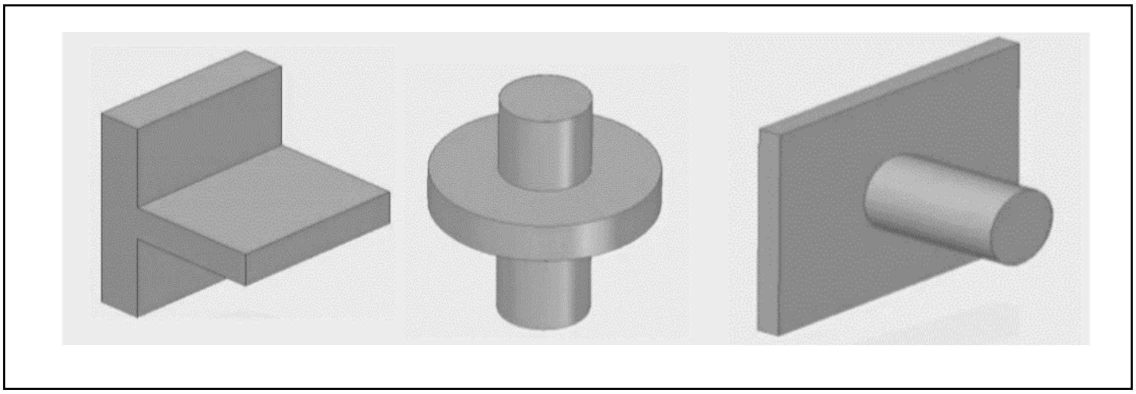


Fig. 1.1: Rectangular, Annular and Pin Fin.[11]

Several types of fins are as shown in above fig. 1.1 out of these fins rectangular fins transfers more amount of heat than annular fin and pin fin[11]. Rectangular fins are of four types: standard rectangular fins, inclined rectangular fins, perforated rectangular fin, interrupted rectangular fin[12]. This paper mainly focuses on standard rectangular fins with semi-elliptical notches.

1.3 Need of Investigation:

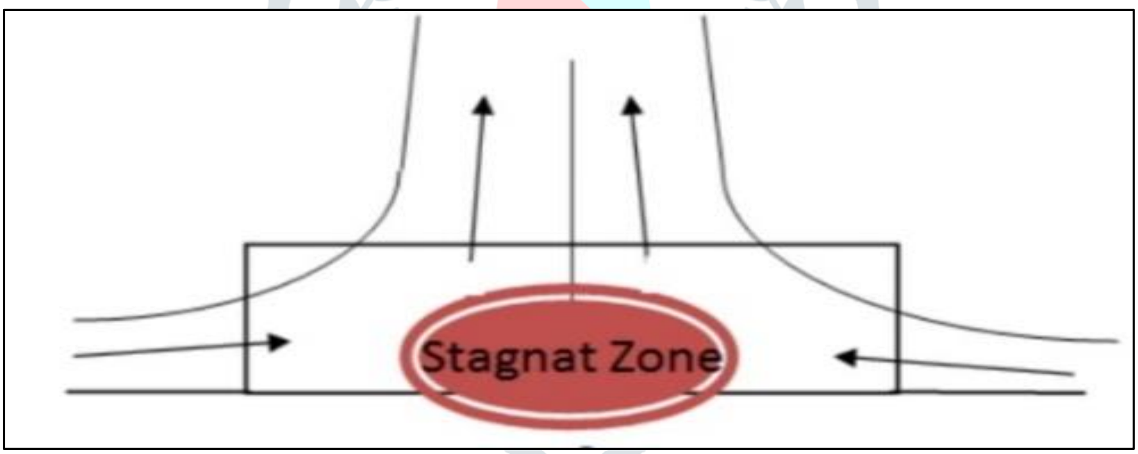


Fig. 1.2: Single Chimney Effect.[13]

Generally, in natural convection heat transfer with vertical fin array on horizontal fin base, it is observed that single chimney flow pattern is there[13] as shown in fig. 1.2. From the early research work and literature survey, there is establishment of single chimney pattern for fin with high aspect ratio[14]. There is sidewise entry of air in case of natural convection cooling of vertical and horizontal fin array. The air coming into the fin array gets heated when it moves towards the central position of the fin array, and it moves upwards due to decrease in density. So, the central bottom portion of the fin becomes less effective or sometimes ineffective because hot airstream passes over that part and therefore it does not bring about large heat transfer through that portion. A stagnant zone is there in the case of rectangular fins at the central bottom portion of a fin array channel which does not contribute much in heat transfer. The area from the stagnant zone is removed in the form of notch and added equally on both sides of fin along the length to modify its geometry for enhancement of heat transfer. This is called **Area compensation**[13]**.** So, in this work we are going to remove the semi-elliptical shaped area from the stagnant zone and compensating this area once at side and once at height to enhance the heat transfer rate. Results are taken at various inputs- 50W, 75W, 100W[3].

2. Literature Survey

S, Taji et. al. [1] showed that triangular perforated fin arrays are 20% to 30% superior to unperforated fin array in terms of average heat transfer coefficient and single chimney flow can be maintained for perforated fin array. Sujan S. [2] studied temperature distribution of cylinder and fins, heat flux through walls by using ANSYS R19.2 and showed that grey cast iron has low thermal conductivity so the rate of heat transfer is comparatively very low, but considering other metals cast iron can withstand high temperatures & the cost is less compared. So, it is mainly used in I. C Engine cylinder. S. Vani et. al.[3] developed v-fins and conclude that v-fins with apex facing downwards configuration, the temperature difference is in the range of 18.06 – 34.16ºC, which is the lowest as compared to any configuration that means this configuration gives the better performance in terms of heat transfer rate. Walid A.[4] conclude that the corrugated profiled fins have an improved heat dissipation capacity than flat fin. Gaoju X. et. al.[5] studied performance of the thermoelectric cooling device with novel sub channel finned heat sink and concludes that thermoelectric refrigeration system using the novel sub channel finned heat sink has a higher coefficient of performance; also, it has a higher heat transfer function than the regular finned heat sink. Pandya B.[6] carried out thermal simulation on different materials with circular fin and conclude that performance of the fin is dependent on fin geometry, fin materials and other parameters like fin height, fin spacing, weight of fin. Chandrakishor L. et. al.[7] carried out comparative analysis of integrated heat sink vapor chamber with conventional heat sink for LED cooling and conclude that temperature distribution in IHSVC is uniform compared to the CHS and IHSVC system more effectively cools the light emitting diode. Adil M. et. al.[8] studied performance of rectangular pin-fin heat sink subject to an impinging air flow and showed that the temperature drop along the extended surfaces is consistently higher as the base heat flux increasing. When Reynolds number increases the heat rejected from the heat sink base increases, which results in increased heat transfer rate from the fin. G. Harish et. al.[9] developed multiple slots on the fin profile of I.C. engine and showed that multiple slots enhance the overall heat transfer rate of engine fins. Vidyasri K. et. al.[10] concludes that Slots or holes or gaps and surface roughness in fins is used to improve heat transfer rate. In the case of circular fins, convex shaped fin has a higher heat transfer rate with reduced material requirement. Suvarna P.[11] carried out experimental analysis of natural convection of heat transfer of different types of notches in fins and showed that the heat transfer coefficient of the set of fins with triangular notch is higher, with increase in size of perforation friction factor of fin increases which will increases the heat transfer rate of fin. Ece A.[12] studied important parameters that affect the heat transfer rate and conclude that Perforated fins have higher heat transfer coefficient than solid fins because number of perforations are directly proportional to Nusselt number.

T. Ramsing et. al.[13] carried out experimentation on rectangular fin array and conclude that making notch is effective method for increasing heat transfer because the values of heat transfer coefficient are higher for notched fin arrays. Elena M. et. al.[14] numerically studied the effect of channels with different aspect ratio on the heat transfer of finned heat sinks with tip clearance and conclude that Nusselt number is higher when aspect ratio lies between 0.25 and 1.75. Hence fins with high aspect ratio have higher heat transfer rate. Sobamowo G.[15] conclude that copper and aluminium porous fin has the highest values of temperature distribution while stainless steel has the least temperature distribution. N. Arul et. al.[16] carried out experimental and computational analysis of various types of fins and showed that rectangular fin transfers more amount of heat when compared to circular and pin fin. Also, the effectiveness of rectangular fin is higher than circular and pin fin. Viveksheel Y.[17] et. al. studied fins with various shapes and materials and conclude that implementation of notches in the design of fins leads to the dissipation of heat from surface and has steady temperature distribution than un-notched fin. Andre M. et. al.[18] conducted compressive analysis by using the CFD software ANSYS 19.1 and developed the novel heat-sink of multiple branches which have higher thermal efficiency. Emilios L. et. al.[19] studied and compared various temperature sensors such as thermocouple, thermal camera, infrared thermometer, fiber optic infrared thermometer and conclude that infrared-thermometer is more accurate than thermocouple, is not affected by heat conduction or heat convection and also provides rapid response for small change in temperature. Ehsan F. et al.[20] investigated transient temperature distribution along constant rectangular fin by using COMSOL software and examined experimentally and conclude that there is 1.2% error between practical results and numerical solutions which goes on decreasing as volumetric air flow increasing. Mehdi K. et. al.[21] carried out experimentation on an array of square fins with various fin spacing and conclude that the optimum fin spacing for the three finned tubes is 9 mm. As increase in fin spacing to some extent increases average heat transfer coefficient. Shitole P. et. al.[22] showed that average Nusselt number (Nu) increases gradually as the ratio of fin spacing to height (S/H) increases for fin array. Vinaya K.[23] carried out experimental analysis of rectangular fin arrays with continuous fin and interrupted fins using natural and forced convection and developed rectangular fins with 4 interrupts which is having higher heat transfer coefficient than other type of fin patterns. Saad N. et. al.[24] developed notched fin array which is having 28% to 45% higher heat transfer rate than that of fin array without notches at the same conditions. Abbas J. et. al.[25] experimentally investigated the effect of different fin spacing, heat flux on performance of vertical rectangular fins under free convection heat transfer and concluded that optimum fin spacing is (6 mm to 12 mm) S=12 mm to get maximum heat transfer coefficient, maximum Nusselt number, and heat transfer rate.

2.1 Research Gap

1. Many of the researchers used the rectangular notched fin array but it was not inverted so that the air does not get more contact surfaces to carry out the heat.
2. In inverted rectangular notched fin array the area removed is greater than so that heat transfer through the conduction decreases.

3. Only a few shaped notches are used, there are many other shapes like trapezoidal, wavy, elliptical, semi-elliptical and so on.

4. There is no proper analysis which shows comparative results of effect on heat transfer rate due to compensation of area at sides along the length with compensation of area at height so as to know better geometry of fin.

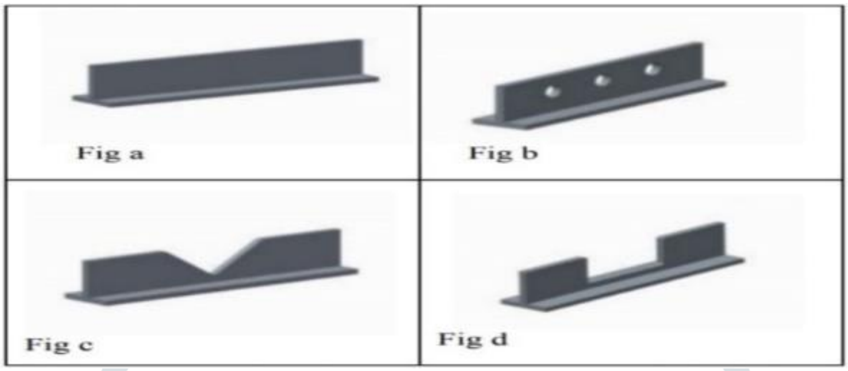


Fig. 2.1: Fin array without Notch and Fins with Various Notches.[17]

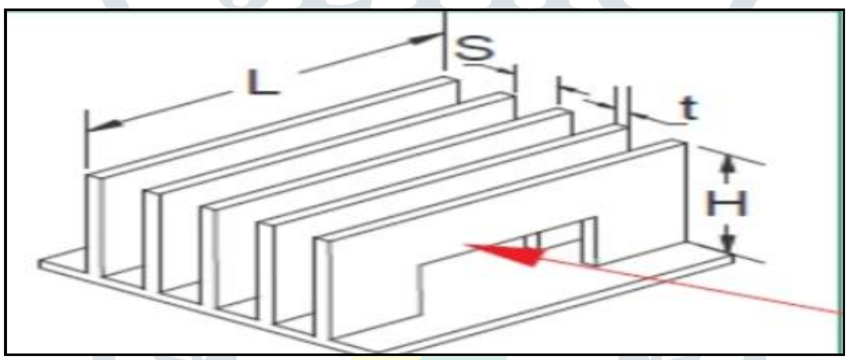


Fig. 2.2: Fin Array with Inverted Rectangular Notch.[13]

2.2 Problem Statement

Advanced electronic circuits which are used in modern electronic applications disperse substantially heavier loads of heat than ever before. At the same time space and weight allocated for cooling purposes is on the decline, which means in the electronic industry microminiaturization of electronic packages is needful.

2.3 Objectives

1. To Study the effect of semi-elliptical notch at central base on convective heat transfer coefficient of fin array at different power input (50W, 75W, 100W).

2. To investigate the rate of heat transfer in notched fin array and un-notched fin array.

3. To compare the effect on heat transfer coefficient due to compensation of notch area at sides along length with compensation of area at height.

3. Methodology:

3.1 Design of Model

In the CPU heat sink rectangular fins of aluminium is used to transfer the heat to maintain the processor cool, so to increase the heat transfer rate from that type of fins the rectangular size of fin is decided. Notch shape selected as semi-ellipse slightly above the base as shown in below figure & Compensation of area removed is to be added at entry side of the air because L/H ratio increases.

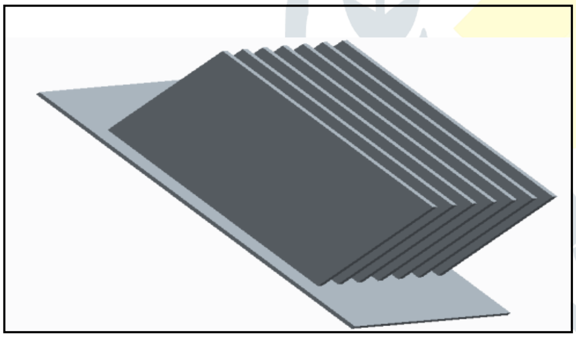


Fig. 3.1: Fin without Notch.

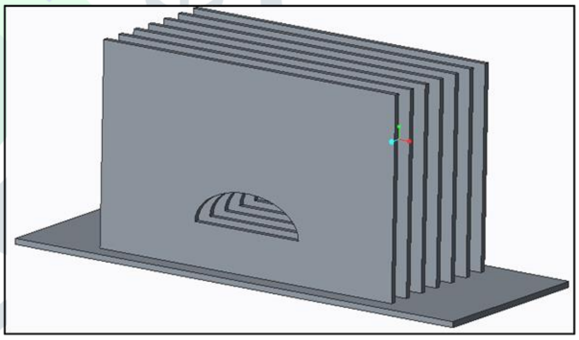


Fig.3.2: Fin with Semi-elliptical Notch.

3.2 Dimensions of Fin Array

Four types of fin arrays were used for experimental analysis.

- Fin array without Notch,
- Fin with notch area removed and compensated along length,
- Fin with notch area removed and compensated at height,
- Fin with notch area removed but not compensated.

Dimensions:

1. Size of base plate = (70mm * 180mm)
2. Thickness of Fins & base plate = 2mm[20], [21]
3. Number of fins = 7 [22], [23]
4. Fin spacing = 7mm[24]

Table 1: Dimensions of Fin Array

Sr. No.	Types of Fins	Height Lc mm	Length (L) mm	Minor Axis (a) mm	Major Axis (b) mm
01.	Fin Without Notch.	70	120	-	-
02.	Fin with 5% notch without compensation.	70	120	12.541	42.640
03.	Fin with 5% notch compensation at both sides.	70	126	12.541	42.640
04.	Fin with 5% notch compensation at height.	73.5	120	12.541	42.640
05.	Fin with 10%notch without area compensation.	70	120	17.736	60.302
06.	Fin with 10% notch compensation at both sides.	70	132	17.736	60.302
07.	Fin with 10% notch compensation at height.	77	120	17.736	60.302
08.	Fin with 15%notch withoutarea compensation.	70	120	21.722	73.855
09.	Fin with 15% notch compensation at both sides of fins.	70	138	21.722	73.855
10.	Fin with 15% notch compensation at height of fins.	80.5	120	21.722	73.855

Table: 1 Continued

3.3

Sr. No.	**Types of Fins**	**Height (h) mm**	**Length (L) mm**	**Minor Axis (a) mm**	**Major Axis (b) mm**
11.	Fin with 20% notch without compensation.	70	120	25.082	85.280
12.	Fin with 20% notch compensation at both sides.	70	144	25.082	85.280
13.	Fin with 20% notch compensation at height.	84	120	25.082	85.280

Experimental Setup

Fig. 3.3: Experimental Setup.

The experimental setup consists of rectangular fin array which is made up of aluminium alloy-1050 [18]placed on rectangular heater plate of size 70 mm x 180 mm. In order to reduce heat loss from other side of base plate an insulating box is provided which is made up of glass wool. This is then enclosed by rectangular enclosure made up of acrylic sheet. To measure temperature industrial temperature gun (IR sensor)[19] is used as there are 13 fin arrays. In many of the experiments k-type thermocouples are used but in this experimentation k-type thermocouples are replaced by industrial temperature gun because IR sensors are not affected by heat conduction or heat convection, and they also provide rapid response. The IR sensors have higher accuracy than thermocouples [19]. The base plate temperature is also recorded by gun (IR sensor). To measure the heat input given to the heater plate digital ammeter (0A to 5A) and voltmeter (0V to 750V) are used and to vary the heat input given to the heater plate a rotary type of dimmer-stat (0 to 230 V) is used.

Experimentation procedure

1. Place rectangular fin array which is without notch on the heater plate.
2. Connect heater wire to control panel and give powersupply to control panel.
3. Put acrylic box around fins as shown in figure.
4. Give 50 watt input supply to heater with rheostat and measure with ammeterand voltmeter readings.
5. Take temperature readings after steady state is reached.
6. Then increase heat input as 50 W, 75 W and100W[25]. follow same procedure for all types of fin array.
7. Cut off power from control panel.

Readings to be taken:

For heater - Input given (50w, 75w, 100w) to take the following readings.

- Temperatures of tip of fin array taken

Each array has 7 fins -- T_1, T_2, T_3, T_4, T_5, T_6, T_7

- Temperature of base plate -- T_b
- Atmospheric temperature -- T_∞

3.4 Formulae Used for Calculations

The formulae that are used for calculating heat transfer coefficient are given below[17]:

1. To find average temperature of fins (T_f)

$$T_f = \frac{T_1+T_2+T_3+T_4+T_5+T_6+T_7}{7}$$

Where, T1, T2, T3, T4, T5, T6 and T7 are the temperatures of tip of fins in ° C.

2. To find temperature of whole body (T_{body})

$$T_{body} = \frac{T_f+T_b}{2}$$

Where, Tb is the temperature of base plate in °C.

3. To find temperature difference between body (Tsurr.) & surrounding temperature (Tsurr)

$$\delta T = (T_{body} - T_{surr.})\ °C$$

4. To find mean film temperature (Tm)

$$T_m = \frac{T_{body}+T_{surr}}{2}\ °C$$

From this temperature find out following properties of fluid, υ = kinematic viscosity of the fluid, m2/s

Pr = Prandtl number

k = Thermal conductivity of fluid, W/mk

5. To find coefficient of volume expansion

$$\beta = \frac{1}{T_m + 273} \; K^{-1}$$

6. To find Grashof number (Gr)

$$Gr = \frac{g\beta\delta T L_c^3}{\upsilon^2}$$

Where,

Lc= height of the fin, m

7. To find Rayleigh number (Ra)

$$Ra = Gr \times Pr$$

If $10^4 < Gr\times Pr < 10^9$ then, $Nu = 0.59\,(Gr\times Pr)^{1/4}$

If $10^9 < Gr\times Pr < 10^{12}$ then, $Nu = 0.59\,(Gr\times Pr)^{1/3}$

8. To find heat transfer coefficient (h)

$$Nu = \frac{hL_c}{k}$$

Where, h is Heat transfer coefficient, W/m^2k.

Using these formulae h is calculated.

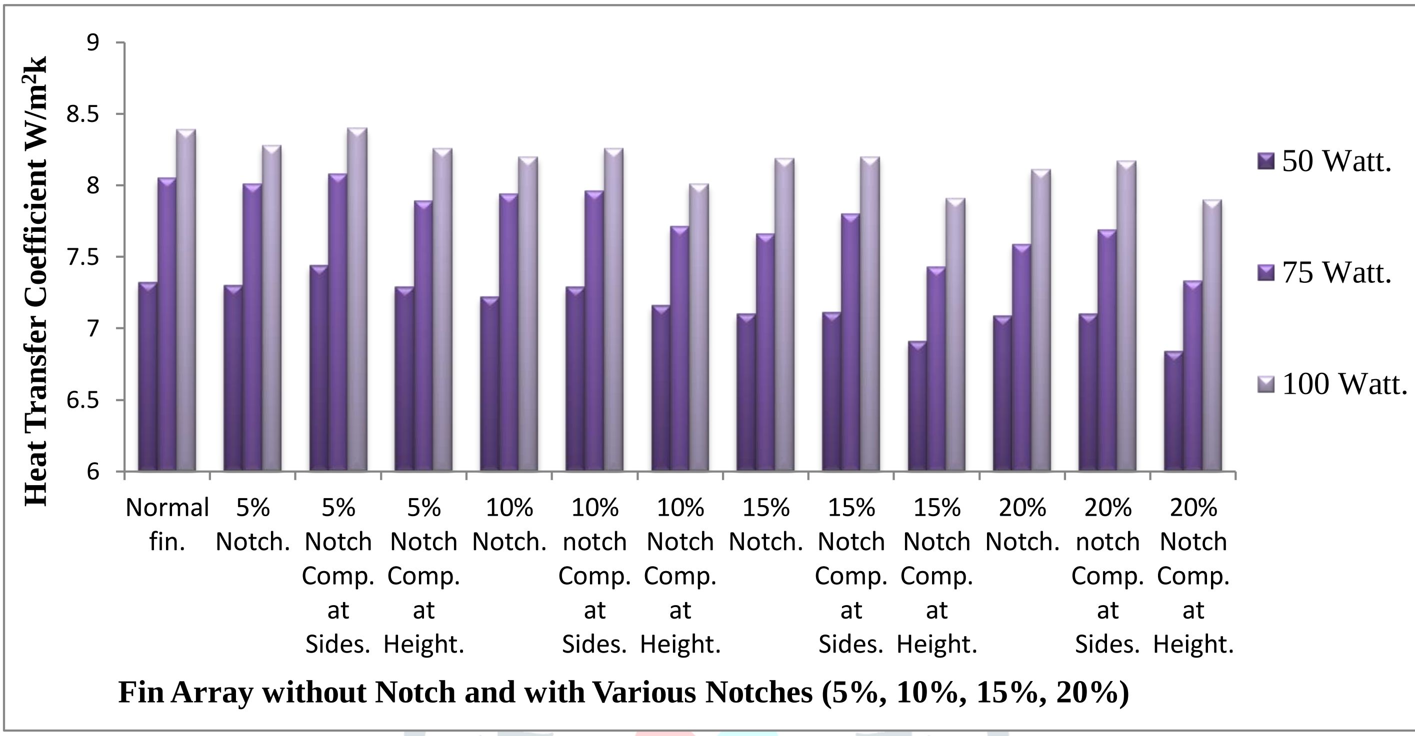
3.5 Observation Table:

Table 2: Heat Transfer Coefficient of Fin Array.

Sr. No.	**Type of Fin Array**	**Heat transfer Coefficient (W/m²k) At 50W, 75W, 100W.**		
1	Normal Fin.	7.32	8.05	8.39

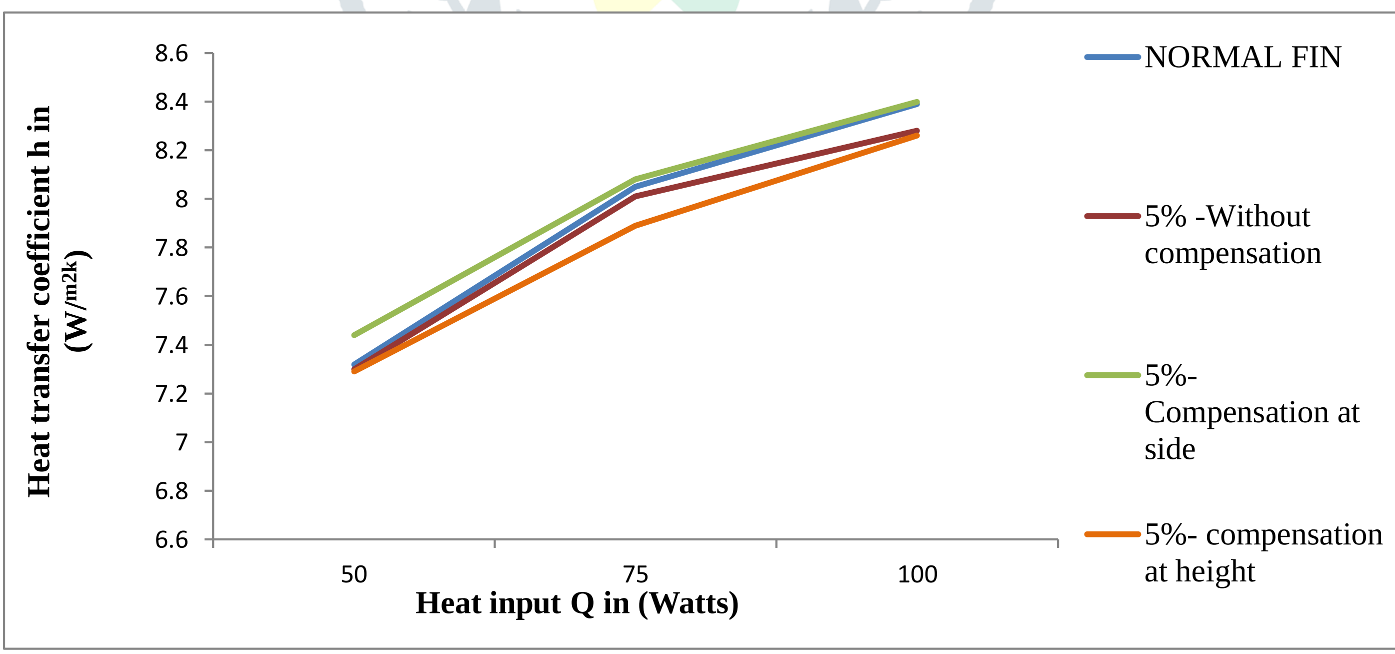
2	5% Notch Fin Array without Area Compensation.	7.30	8.01	8.28
3	5% Notch Fin Array with Area Compensation at Sides.	7.44	8.08	8.40
4	5% Notch Fin Array with Area Compensation at Height.	7.29	7.89	8.26
5	10% Notch Fin Array without Area Compensation.	7.22	7.94	8.20
6	10% Notch Fin Array with Area Compensation at Sides.	7.29	7.96	8.26
7	10% Notch Fin Array with Area Compensation at Height.	7.16	7.71	8.01
8	15% Notch Fin Array without Area Compensation.	7.1	7.66	8.19
9	15% Notch Fin Array with Area Compensation at Sides.	7.11	7.8	8.2
10	15% Notch Fin Array with Area Compensation at Height.	6.91	7.43	7.91
11	20% Notch Fin Array without Area Compensation.	7.09	7.59	8.11
12	20% Notch Fin Array with Area Compensation at Sides.	7.1	7.69	8.17
13	20% Notch Fin Array with Area Compensation at Height.	6.84	7.33	7.9

4. Results and Discussion



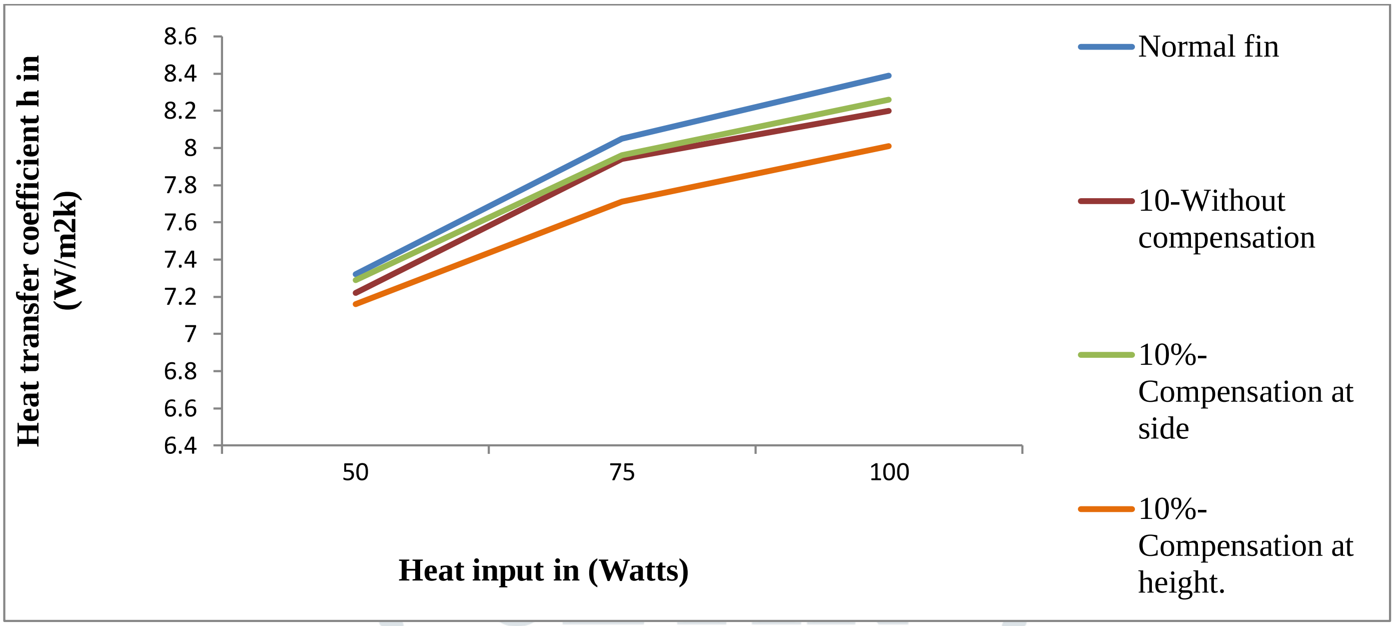
Graph 1: Heat Transfer Coefficient for Various Fin Arrays at 50W, 75W and 100W Input.

From information of table 2 graph 1 is drawn. Above graph shows that for 5% notched fin array with area compensation at sides have higher heat transfer rate than fin array without notch, but when notch percentage is more than 5% then heat transfer rate decreases.



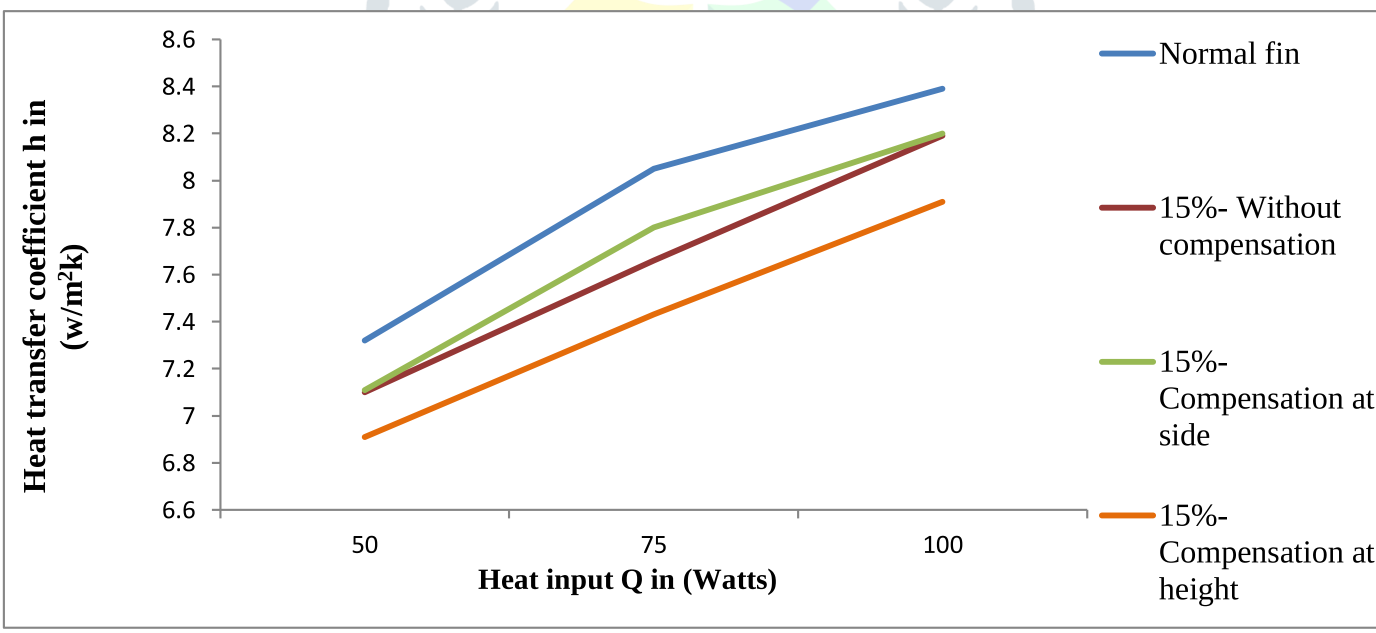
Graph 4.2: Heat Input Vs Heat Transfer Coefficient for Normal and 5% Notch Fin Array.

From information of table 2, graph 4.2 is drawn. From graph it is observed that heat transfer rate at 50W, 75W and 100W for 5% notched fin array with area compensation at side is higher than normal fin array.



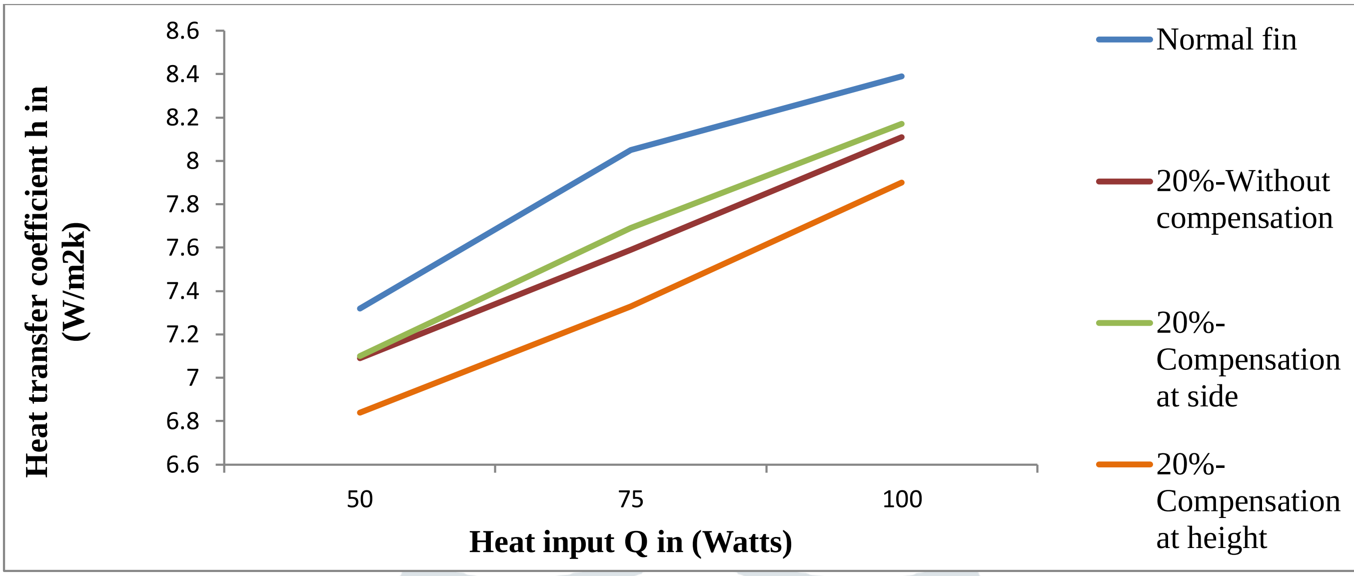
Graph 4.3: Heat Input Vs Heat Transfer Coefficient for Normal and 10% Notch Fin Array.

From information of table 2, graph 4.3 is drawn. From graph it is observed that heat transfer rate for normal fin array is higher than 10% notched fin array with and without area compensation. This shows that as notch area increases heat transfer rate decreases for notched fin array.



Graph 4.4: Heat Input Vs Heat Transfer Coefficient for Normal and 15% Notch Fin Array.

From information of table 2 graph 4.4 is drawn. From graph it is observed that heat transfer rate for normal fin array is higher than 20% notched fin array with and without area compensation.



Graph 4.5: Heat Input Vs Heat Transfer Coefficient for Normal and 20% Notch Fin Array.

From information of table 2 graph 4.5 is drawn. From graph it is observed that heat transfer rate for normal fin array is higher than 20% notched fin array with and without area compensation.

5. Conclusion & Future Scope

5.1 Conclusion

Experimental analysis is done on 13 types of fin array i.e., fin without notch, fin without compensation of notch area, fin with compensation of notch area at side and fin with compensation of notch area at height for 5%, 10%, 15% and 20% notch. I have used this area compensation method by removing material from central base area just above the base in the form of semi-elliptical notch and carried out comparative study on effect of compensation area at different locations on heat transfer rate. The conclusions drawn from this study are given below.

1. Heat transfer coefficient is higher for 5% notched rectangular fin array with compensation of area at side than other type of fin array.

2. As the rate of area removal increases than 5% heat transfer coefficient decreases. As heat transfer coefficient of fin array without notch is higher than 10% notched fin array. Means increasing notch area reduces heat transfer rate.

3. Fin array with area compensation at height have lower heat transfer rate than area compensation at side for all types of fin array, as Nusselt number for this type of fin array is higher but due to increased height value of heat transfer coefficient decreases.

4. Nusselt number increases with increase in heat input.

5. With increase in heat input, heat transfer coefficient increases for all types of fin array whether it is

notched or without notched fin array.

5.2 Future Scope

Following future work can be performed for further research.

1. Till now study has carried out on available shapes like rectangular, circular, triangular, elliptical and semi-elliptical. So other can use fin array with complex shapes like wavy array with notch, coated fin array with different types of notches.

2. One can try for varying notch area and vary dimensions of fin also.

3. As 5% notched fin array with area compensation gives higher heat transfer rate it means that area removal below 5% gives higher heat transfer rate so study on this is also important.

4. Study on transient analysis for notch fin.

5. Although the previous investigative study reveals that there is maximum heat transfer for triangular notches, probably there would be other shapes for which rate of heat transfer would be maximum.

References

[1] D. Saurabh and S. G. Taji, "International Journal of Current Engineering and Technology Convection Heat Transfer from Horizontal Rectangular Fin Array having Triangular Perforations." [Online]. Available: http://inpressco.com/category/ijcet

[2] Y. Nitesh, S. Shrestha, N. Kumar Yadav, and S. Bikram Bam, "ANALYSIS OF HEAT TRANSFER THROUGH FINS OF IC ENGINE Design and Fabrication of Electromagnetic Brakes incorporate with Electronic Brake Force Distribution. View project ANALYSIS OF HEAT TRANSFER THROUGH FINS OF IC ENGINE." [Online]. Available: https://www.researchgate.net/publication/334825457

[3] A. Wani, S. Pol, A. Mane, and M. S. P. Mane, "EXPERIMENTAL INVESTIGATION OF NATURAL CONVECTION HEAT TRANSFER FROM A BLACKENED V-FIN ARRAY."

[4] R. Rangappa, W. A. Al-Suraihi, and G. Vikas, "Effects of Corrugation Profile on the Heat Transfer Rate of Fins Entrepreneurship Orientation and Entrepreneurship Intention View project Renewable Energy Project View project Eects of Corrugation Prole on the Heat Transfer Rate of Fins." [Online]. Available: https://www.researchgate.net/publication/327781164

[5] G. Xia *et al.*, "Study on performance of the thermoelectric cooling device with novel subchannel finned heat sink," *Energies (Basel)*, vol. 15, no. 1, Jan. 2022, doi: 10.3390/en15010145.

[6] B. Pandya, P. Bhavik, and M. C. Karia, "A BRIEF OVERVIEW OF APPLICATION OF EXTENDED SURFACES (FINS) FOR ENHANCEMENT OF HEAT TRANSFER GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES A BRIEF OVERVIEW OF APPLICATION OF EXTENDED SURFACES (FINS) FOR ENHANCEMENT OF HEAT TRANSFER", doi: 10.5281/zenodo.2578915.

[7] C. Ladekar, A. Pise, M. Nukulwar, and A. Lingayat, "Comparative analysis of integrated heat sink vapor chamber with conventional heat sink for LED cooling," *Mater Today Proc*, vol. 72, pp. 1136–1142, Jan. 2023, doi: 10.1016/j.matpr.2022.09.184.

[8] A. A. Mohammed and S. A. Razuqi, "Performance Of Rectangular Pin-Fin Heat Sink Subject To An Impinging Air Flow," *Journal of Thermal Engineering*, vol. 7, no. 3, pp. 666–676, 2021, doi: 10.18186/THERMAL.889174.

[9] N. M. Das A., H. G., P. D., S. J., and S. G., "Transient thermal analysis of different types of IC engine cylinder fins by varying thickness and introducing slots," *Journal of Mechanical Engineering Research*, vol. 12, no. 1, pp. 1–18, Jan. 2021, doi: 10.5897/jmer2020.0536.

[10] V. Khadanga, M. Vara, and P. Rao, "Issue 4 IJRAR1904375," *International Journal of Research and Analytical Reviews*, vol. 5, 2018, [Online]. Available: www.ijrar.org

[11] S. Patil *et al.*, "Experimental Analysis of Natural Convection of Heat Transfer of Different Types of Notches in Fins: A Review Evaluation and Optimization of Warpage in Injection Molded Nylon-66 Bevel Gear View project Experimental Analysis of Heat Exchanger for Enhancement of Heat Transfer with Different Concentrations of TiO2 Nano Fluid View project Experimental Analysis of Natural Convection of Heat Transfer of Different Types of Notches in Fins: A Review," 2017. [Online]. Available: www.ijsrd.com
[12] E. Ayli and E. İnce, "REVIEW OF ENHANCEMENT OF HEAT TRANSFER FROM RECTANGULAR FIN ARRAYS," *Mugla Journal of Science and Technology*, pp. 162–174, Dec. 2018, doi: 10.22531/muglajsci.445045.
[13] "13--pic431-Article Text-1020-1-10-20180416".
[14] E. Martin, A. Valeije, F. Sastre, and A. Velazquez, "Impact of Channels Aspect Ratio on the Heat Transfer in Finned Heat Sinks with Tip Clearance," *Micromachines (Basel)*, vol. 13, no. 4, Apr. 2022, doi: 10.3390/mi13040599.
[15] G. Sobamowo, M. Salami, M. G. Sobamowo, T. O. C. Agbelusi, and M. O. Salami, "Finite Element Thermal Analysis of Electronic Heat Sinks of Convex and Concave Parabolic Porous Fins with Temperature-dependent Thermal Properties and Internal Heat Generation", [Online]. Available: www.worldscientificnews.com
[16] N. Arul, G. Srinivasan, K. Sriram, M. Vignesh, S. Vijayaraj, and U. G. Students, "Experimental and Computational Analysis of Various Types of Fins."
[17] S. Zaidshah and V. Yadav, "Heat transfer from different types of fins with notches with varying materials to enhance rate of heat transfer a Review." [Online]. Available: http://www.ripublication.com
[18] A. Mueller, C. Buennagel, S. Monir, A. Sharp, Y. Vagapov, and A. Anuchin, "Numerical Design and Optimisation of a Novel Heatsink using ANSYS Steady-State Thermal Analysis," in *2020 27th International Workshop on Electric Drives: MPEI Department of Electric Drives 90th Anniversary, IWED 2020 - Proceedings*, Institute of Electrical and Electronics Engineers Inc., Jan. 2020. doi: 10.1109/IWED48848.2020.9069568.
[19] E. Leonidas, S. Ayvar-Soberanis, H. Laalej, S. Fitzpatrick, and J. R. Willmott, "A Comparative Review of Thermocouple and Infrared Radiation Temperature Measurement Methods during the Machining of Metals," *Sensors*, vol. 22, no. 13. MDPI, Jul. 01, 2022. doi: 10.3390/s22134693.
[20] E. Fadhil, H. Hayder, M. Ali, and N. Jalal, "Comparison Between Numerical Study and Experimental Work on Heat Transfer from Heat Sink Under Transient Conditions," 2021. [Online]. Available: https://www.researchgate.net/publication/352546023
[21] M. Karami, M. Yaghoubi, and M. Yaghoubi, "Experimental Study of Natural Convection from Arrays of Square Fins with Various Fin Spacing Transient simulation of a hybrid photovoltaic-thermoelectric system using a phase change material View project Investigation on domical roofs of Iran traditional bazaars View project Experimental Study of Natural Convection from Arrays of Square Fins with Various Fin Spacing." [Online]. Available: https://www.researchgate.net/publication/322755031
[22] S. Pankaj, B. Santosh, K. Kishor, and J. Sarang, "Experimental Investigation of Heat Transfer by Natural Convection with Perforated Pin Fin Array," in *Procedia Manufacturing*, Elsevier B.V., 2018, pp. 311–317. doi: 10.1016/j.promfg.2018.02.046.
[23] V. Kumara, M. Krishnamurthy, A. Deep, and P. G. Student, "Experimental Analysis of Rectangular Fin Arrays with Continuous Fin and Interrupted Fins Using Natural and Forced Convection," *International Journal of Innovative Research in Science, Engineering and Technology (An ISO*, vol. 3297, 2007, doi: 10.15680/IJIRSET.2016.0508063.
[24] S. Najeeb Shehab, "Experimental Study of Free-Convection from Rectangular Fins Array on a Heated Horizontal Plate with Notch Effects," 2017.
[25] A. J. Jubear and A. J. Jubear Al-Jassani, "EXPERIMENTAL STUDY FOR OPTIMUM FIN SPACING OF RECTANGULAR FIN ARRANGEMENTS UNDER THE INFLUENCES OF FREE CONVECTION," 2020. [Online]. Available: https://www.researchgate.net/publication/348607330