Review Paper on Experimental Investigation of Permeable Fins

Viraj K. Warang[1], Bhalchandra S. Parkar[2], Shriram A. Sawant[3], Prasad P. Adivrekar[4], Aniket S. Pendse[5]

[1,2,3,4]U.G. Students, Dept. Of Mechanical Engineering, S.S.P.M's College of Engineering, Mumbai University, Maharashtra, India

[5]Professor, Dept. of Mechanical Engineering, S.S.P.M' s College of Engineering, Mumbai University, Maharashtra, India

---***---

Abstract – *The primary objective of this study is to quantify and compare the convective heat transfer improvement of perforated fin assemblies with different fin spacing, perforation angle, perforation diameter, perforation spacing, and heater input. The variables for this natural convection cooling with fin surfaces are orientation and geometry. In this study, steady-state heat transfer from solid and perforated fin assemblies is measured. In this study, we specify an optimized fin configuration for various fin shape parameters and their impact on heat transfer results. The results obtained are in good agreement, showing similar trends and good agreement for heat transfer under natural convection. From all the results it can be concluded that the heat transfer coefficient of the fin with the maximum number of perforations and the perforations in the middle of the fin gives the best results. A rib arrangement with triangular perforations with a 90 degree slope is best suited for horizontal rectangular rib arrangement for natural conventions, followed by circular, rectangular, and non-perforated ribs. The perforation geometry of the fins has a great effect on convective heat transfer.*

***Key Words:** Permeable fins, Heat transfer rate, perforated fins, Natural Convection, Fin arrays*

1. INTRODUCTION

Convection is the mode of heat transfer between a surface and a liquid moving over it. Energy transfer in convection is primarily due to the bulk motion of fluid particles, but molecular conduction within the fluid itself also contributes to some extent. If this motion is primarily due to density changes associated with temperature gradients within the fluid, the mode of heat transfer is said to be due to free or natural convection. On the other hand, fluid motion is mainly generated by superimposed velocity fields (fans, blowers, pumps, etc.), and energy transport is said to be due to forced convection.

We know that removing heat from a system is very important, so systems employ heat sinks to extract heat from the system by exchanging the extracted heat with another fluid or environment. Increase. According to Newton's Law of Cooling, this can be done in two ways:

i. Increasing heat sink surface area

ii. Increasing heat transfer coefficient

Increasing the heat transfer rate requires installing a pump or fan, or replacing the existing one with a larger one, but this approach may or may not be practical. In some cases. Alternatively, extended surfaces called fins made of a highly conductive material such as aluminium can be attached to the surface to increase the surface area. Such ribbed surfaces are commonly used in practice to improve heat transfer, often increasing the heat transfer rate through the surface many times.

A review of the literature reveals that perforated fin assemblies have been tried using square, triangular, and circular perforated fin assemblies to improve heat exchange. It can be seen that for natural convection, the heat transfer coefficient depends on the orientation and shape change of the fin assembly.

2. REVIEW

2.1 Pramod R. Dabhade

This paper investigates the trial examination of natural convection heat transfer from horizontal rectangular fins array with blind holes. The effect of surface area of fins array were identified as the main controlling parameters for the heat transfer augmentation .Heat transfer coefficient was found to be increased with the increase in the diameter of the perforated fins.Three fin array blocks of aluminum with 4 mm, 6 mm & 8 mm perforation diameter and 6 mm fin spacing were experimentally tested at various input powers 40W, 60W, 80W, 100W, 120W. Another parameter being various inclinations (0-90) of the fins.

From this study we concluded as the surface area increases the heat transfer coefficient increases. Convection heat transfer coefficient increases with the increase in fin inclination from 0-90. For the given input, heat exchange coefficient of array with blind holes is higher than the relating solid one. [1]

2.2 Wadhah Hussein

The experimentation on heat exchange through fins with circular holes is examined in this work. In this study, the rectangular flat fins are altered by circular holes being drilled into them. The goal of the study was to better understand how heat moves through a rectangular fin plate with circular holes acting as heat sinks naturally. The initial fin had 24 circular perforations (holes), and each subsequent fin had eight more, for a total of 56 perforations by the time the fifth fin was present. There were 614 rows and 4 columns of these holes.

It was concluded from this that the temperature reduction for the perforated fins was greater than for the non-perforated fins. Also, it is inferred from this study that the fins with the most perforations have the most astonishing convective heat transfer coefficient. According to the investigation, the perforated fins with a higher number of perforations had a higher heat transfer coefficient than those with fewer perforations. [2]

2.3 Osama Raad

This study examines the enhancement of natural convection heat transfer in rectangular plate-fins with perforations at the top, middle, and bottom. The goal of the investigation was to determine how perforations, perforation diameters, and perforation placements affected the thermal performance of solid fins during conditions of natural convection heat transfer. Six different aluminium fin arrangement options make up the setup. Three different combinations use rectangular plane fins with perforations that are 3 mm, 5 mm, and 7 mm in diameter. The remaining three variants placed a matrix with three columns and ten rows, totaling thirty circular perforations, at the bottom, top, and middle of the flat plate fin.

Each fin has an outside size of 110 mm in length, 1 mm in thickness, and 100 mm in breadth. All the tested fins are receiving a steady heat flux in the meantime. Findings showed that regardless of the diameter, the perforations at the centre of the perforated fins produce the greatest gain in thermal performance. Also, regardless of the perforations placements, it was discovered that 3 mm perforations performed better thermally than 5 mm & 7 mm perforations. [3]

2.4 Maha A. Hussein

In the paper, we investigate the influence of the newly proposed tile fin geometry on the thermal performance in heat sinks under natural convection conditions. It has 6 fins and its material is aluminum. Each rib is 3mm thick, 240mm long and 100mm wide. These six fins were attached through longitudinal slots around the cylindrical heat sink. The first type of fin set was flat (fin 1), the second type was a square rim (fin 2) and the last type had a circular hole and a square fin rim (fin 3). The parameters considered in this study were:

1. Drill holes by changing the shape, position, diameter, arrangement and number of holes.
2. Cut the parts by changing the shape, number and position to be cut.
3. Rib material, thickness, direction, weight and length.

The power values delivered were 37.5 V, 50 V, 62.5 V, and 75 V for all fin settings. Different values of heat loss were 4.02395%, 2.6044% and 2.3212% for fin (1), fin (2) and fin (3) respectively. The tested fin (3) was found to dissipate 6.8% and 12.9% more heat than fins (2) and (1) respectively. The average effects of the investigated fins were 2.9, 3.1 and 3.3 for fins (1), (2) and (3), respectively. Efficiencies of all proposed fin geometries were above 90%. [4]

2.5 Akhilesh Kumar Singh

This paper examines the investigation of the effect of increase in perforation diameter and angle of inclination on the natural convection heat transfer from rectangular fin array. In this paper, the natural convection heat transfer under steady state condition from the solid fin array and the perforated fin arrays with 4 mm fin spacing, fin perforation diameter (4,6 and 8 mm) & fin inclination angle (0, 30, 45, 60 and 90) were analyzed & compared.

Experimentation was carried out on configuration with 10 fins. Dimensions of fin and base plate made of aluminum material are taken as (75*27*2mm) and (76*75*2mm) respectively. Heat input was provided as 15 W, 25 W, 35 W, 45 W. Result implies that the enhancement in the heat transfer coefficient was achieved with the increase in the fin perforation diameter. With the variation in fin inclination angle from 0 to 90 also the heat transfer was enhanced. [5]

2.6 Basima S. Khalaf

In this paper, experiments were done to investigate the natural and forced convection of heat transfer along a flat surface equipped with various types of rectangular aluminum fins (solid and perforated). Selected rib with dimensions (30 mm high x 30 mm wide x 1 mm thick). Perforated ribs have different distributed holes (2mm for 9 holes, 4mm for 5 holes). Aluminum is used for the ribs and floor material. Natural convection modes of heat transfer along perforated and non-perforated fins were analyzed in steady state.

The effects of the number, size and arrangement of perforated lamellae were investigated. A higher heat transfer rate is observed with an increased number of circular holes, and efficiency is also improved due to the reduced weight of the fins. A numerical analysis was also performed to examine this temperature distribution and used in a simulation program (SOLDWORKS). Good agreement was found when comparing experimental and theoretical studies. Some observations from this study can be summarized as follows:

1. The temperature difference between the base and tip of the perforated fin was larger than that of the non-perforated fin.
2. The heat transfer coefficient of perforated fins depends on the dimensions of the holes and the width of the fins.
3. The heat transfer coefficient increased as the number of holes increased. [6]

2.7 Rashin Nath K.K

In this work, they numerically investigate the effect of different fin geometries on the overall heat transfer from an air-cooled fin assembly mounted on a cylindrical surface. In this paper, the heat transfer and heat transfer coefficient of three fin models (rectangular, wavy and zigzag) were studied. The structure was modeled with CATIA V5 software and thermally analyzed using ANSYS Fluent software. A cylinder with three ribs used for CFD analysis. The aluminum slat dimensions are assumed to be 220 x 150 x 1 mm. The outer diameter of the cylinder is 72mm. 70mm inner diameter, 1mm thickness. The length of the cylinder is 80mm.

Next, we compared the heat transfer coefficients of different geometries. At low speeds, flat fins were found to have higher heat transfer coefficients and heat transfer coefficients. The heat transfer coefficients of the zigzag and wave fins increased with increasing vehicle speed compared to the flat fins. The development of a curved zigzag shape can create vortices between the two fins, creating turbulence and increasing heat transfer. [7]

2.8 Ashok Tukaram Pise

Ashok Tukaram Pise conducted experiment for comparing the heat transfer coefficients of solid and permeable fins. The permeable ribs are formed by altering the solid rectangular ribs by drilling three holes per rib, inclined at half the rib length of the two-wheel cylinder block. Solid, permeable rib blocks were kept in an isolated chamber and the efficacy of each rib in these blocks was calculated.

An engine cylinder block with solid permeable fins was tested at various power inputs (i.e. 75W, 60W, 45W, 30W, 15W). We found that the permeable fins improved the average heat transfer coefficient of the block by about 5.63%, increasing the average heat transfer coefficient by 42.3% compared to the solid fins, and reducing the material cost by 30%. [8]

2.9 Mahathir Mohammad

This experimental study was conducted to investigate the effect of extended surface perforation shape or geometry on forced convection heat transfer, finding the heat transfer properties of various perforated fins to reveal the optimal perforation geometry for planar heat sinks. Studies have shown that the temperature drop along perforated ribs was greater than without perforations. For the heatsink we used a solid aluminum block 190mm long, 120mm wide and 7mm thick. The rib was 120 mm long, 85 mm wide and 4 mm thick. Each fin is spaced 38mm apart for even heat distribution. To minimize heat loss from the baseplate and finplate, the finplate was placed 3mm inside the baseplate and was also soldered to the baseplate and fins to reduce heat loss. The parameters studied were temperature distribution and heat transfer coefficient. The average increase in convective heat transfer coefficient at 150W is 78.98% for triangles and fins without holes, which is greater than for rectangles (74.36%) and circles (41.42%). A similarity can be seen for 100W power consumption, with triangular perforated fins exhibiting the highest temperature difference at 54.59%, followed by rectangular at 38.0% and circular at 33.04%.

From this study it can be concluded that, Fin holes and hole geometry had a significant impact on the temperature distribution across the fin, which affects the fin's performance. A triangular perforated shape gives the best results, followed by rectangular and circular. [9]

2.10 G. M. Sobamowo

In this study, investigation on the thermal responses of moving irregular porous fins with trapezoidal, concave, and convex profiles of copper, aluminum, silicon nitrides and stainless-steel materials were examined. The developed thermal model is solved using differential transform method (DTM).

In the parametric studies carried out, the effect of physical parameters such as convective-conductive, convective-radioactive term, internal heat generation, porosity, surface emissivity, power index of heat transfer coefficient, Peclet number and Darcy number on the thermal behavior of fins were examined and discussed. The comparative analysis carried out on the effect of materials on non-dimensional temperature distribution reveals that copper obtains the highest temperature while the stainless steel gets the lowest. More-so, the fins with concave geometry gives the highest volume adjusted efficiency with increase in Peclet number while that with convex profile has the least.

The conclusions made from the experimentations are clear that these result outputs are essential and would be useful in the future design of fins with optimum size reduction and high efficiency. [10]

TABLE -1: Comparison of Parameters

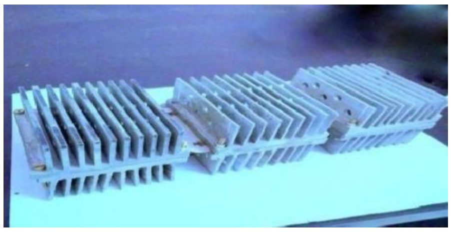
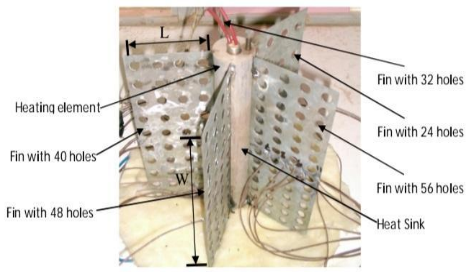
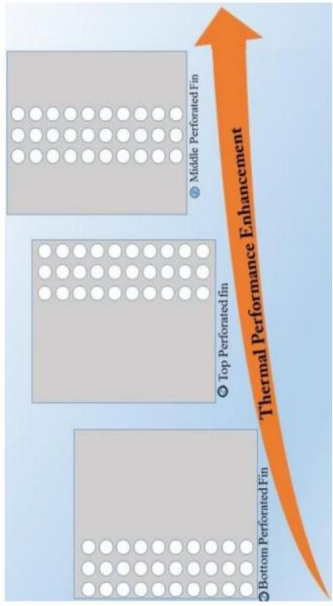
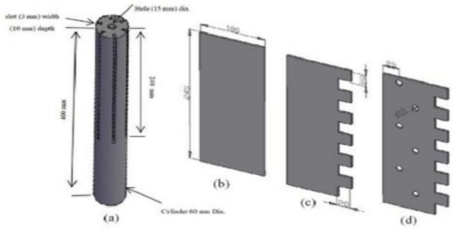
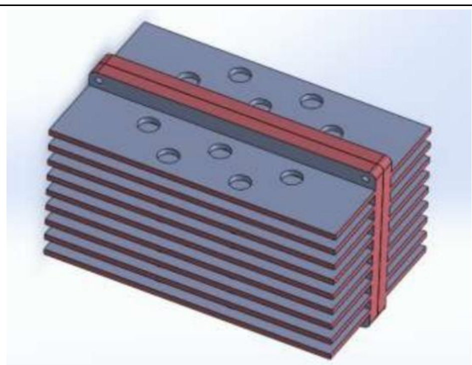
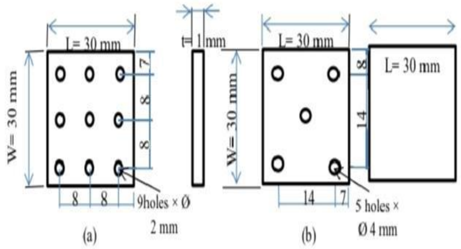
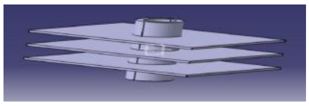
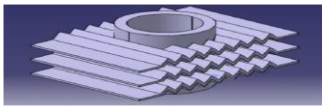
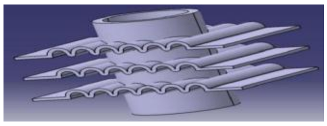
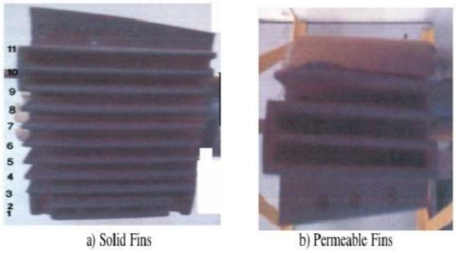
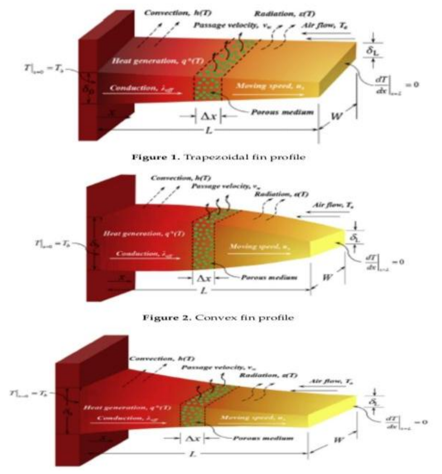
<table>
<tr><th>NAME OF AUTHOR</th><th>MODIFICATIONS</th><th>PARAMETERS STUDIED</th><th>ENHANCEMENT ACHIEVED</th><th>GEOMETRY</th></tr>
<tr><td>Pramod R. Dabhade [1]</td><td>Rectangular fins with Blind holes</td><td>Surface area of fins</td><td>Heat transfer rate is maximum in perforated fins with Blind holes as compared to fins with complete holes. (i.e., heat transfer rate is depends upon the surface area of fins.</td><td>
Fig 1– Fin Array Block (Pramod R. Dabhade et all, 2019)</td></tr>
<tr><td>Wadhah Hussein [2]</td><td>Rectangular fins plate with circular perforations (complete holes)</td><td>No. of perforations - 24,32,40,48,56
Dia. of perforations - 12 mm
(i.e. variation in no. of perforations with constant diameter)</td><td>Temperature drop in perforated fins is higher than non-perforated fins.
Heat transfer rate increases with no. of holes increases.</td><td>

Fig 2– View of the Heat Sink (Wadhah Hussein et all, 2011)</td></tr>
</table>

Osamah Raad [3]	Rectangular fins with perforations having perforated positions like bottom, middle, top.	**Perforations diameter -** 3,5,7 **No. of perforations (holes) -** 30 (i.e., variations in dia. of perforations with constant no. of holes) **Perforations positions** – (Top, Middle, Bottom) **Fin dimensions –** **Length -** 110 mm, **Width -** 100mm **Thickness -** 1mm	Perforations positioned at the middle of the fin regardless of the dia. gives maximum improvement in the thermal performance.	 **Fig 3–** Graphical Abstract (Osamah Raad et all, 2020)
Maha A. Hussein [4]	Fins with rectangular edge, and fins with circular perforations with a rectangular edge	**Material –** Aluminium **Fin dimensions -** Length - 24 cm Width - 10 cm Thickness - 3mm	Heat sink with circular perforations with a rectangular fin edge gives maximum performance, heat dissipation, and minimum fins weight and cost.	 **Fig 4–** The schematic experimental rig (Maha A. Hussein et all, 2021)
Akhilesh Kumar Singh [5]	**Hole pattern -** Zigzag **Hole size**	**Fin dimensions –** **Length -** 75 mm **Width -** 27 mm **Thickness -** 2 mm **Effect** of perforations diameter & fin inclination	Increase in heat transfer coefficient with the increase in diameter of holes. Also heat transfer rate increases when the fin inclination is varied from 0° to 90°.	 **Fig 5 –** Fin Array Block (Akhiles Kumar Sing et all, 2017)

Basima S. Khalaf [6]	Square fins with circular perforations	**Fin dimensions -** **Length -** 30 mm **Width -** 30 mm **Thickness -** 1mm **1]** 9 holes *dia.2mm **2]** 5 holes *dia.4mm	The temperature difference between base and tip of perforated fins is greater than for those of non-perforated fins.	 **Fig 6 –** Perforated Fins (Basima S. Khalaf et all, 2020)
Rashin Nath KK [7]	Fins with different geometries (rectangular, zigzag, wavy)	**Heat transfer & heat transfer coefficient** of conventional, zigzag & wavy fin models.	Heat transfer rate of conventional fins are greater for low velocity w.r.t. that of zigzag & wavy. Zigzag & wavy fins can be preferred over conventional fins for higher speed vehicles as it induces greater turbulence and thus greater heat transfer rate.	 (a)  (b)  (c) **Fig 7 –** (a) Wavy Fin, (b) Zig Zag Fin, (c) Conventional Fin (Rashin Nath KK et all, 2017)
Ashok Tukaram Pise [8]	Rectangular fins with circular perforations in application for 2-wheeler cylinder block.	**Fin dimensions -** **Length -** 110 mm **Width -** 66 mm **Thickness -** 5mm **Perforations (hole) diameter** - 5mm	For the same heat transfer, the material removed by mass in permeable fins is about 10-30%. Therefore, reduction in material cost is 30%.	 **Fig 8 –** Images of Fins (Ashok Tukaram Pise et all,2010)
Mahathir Mohammad [9]	Circular, rectangular & triangular perforated fins	**Fin dimensions -** **Length -** 120 mm **Width -** 85 mm **Thickness -** 4 mm	Heat transfer coefficient increases most for triangular perforations followed by circular, rectangular and no perforations. Perforation shapes of fins shows a significant effect in convention heat transfer.	 **Fig 9 -** Heat Sink Design (Mahthir Mohammad et all, 2019)

G. M. Sobamowo [10]	Fins with trapezoidal, concave & convex profiles of copper, aluminium, and stainless steel	**Effect of different materials with different profiles** on heat transfer rate	Copper obtains the highest temperature while the stainless steel gets the lowest. Fins with concave geometry gives the highest volume adjusted efficiency while convex profile has the least.	 **Fig 10 –** (a) Trapezoidal Fin Profile, (b) Convex Fin Profile, (c) Concave Fin Profile (G. M. Sobamowo et all, 2019)

3. CONCLUSION

From the above, we can obtain a basic understanding of various parameters such as fin shape and orientation when structuring a heat sink. The heat transfer coefficient increases with the number of perforations and the size of the perforations. It has also been observed that a hole in the center of the fin gives the optimum heat transfer coefficient.

Moreover, it is well justified that triangular perforated fins give higher heat transfer coefficients, followed by circular rectangles than regular (non-perforated) fins. The perforation geometry of the fins has a great influence on the convective heat transfer. The performance of perforated fin arrays is very good compared to regular fin arrays.

A literature review therefore provides preliminary evidence that perforated fin heat sinks are most commonly used for practical heat transfer applications compared to plate fin heat sinks. This extensive study will help future heatsink design studies.

REFRENCES

[1] Pramod R. Dabhade, Prof. N. S. Payaghana, "A Review Paper on Heat Transfer Rate of Fins with Blind Holes in Natural Convection" (IJERT) Volume & Issue: Volume 08, Issue 08 (August 2019) ISSN (Online): 2278-018

[2] Wadhah Hussein Abdul Razzaq Al- Doori, "ENHANCEMENT OF NATURAL CONVECTION HEAT TRANSFER FROM RECTANGULAR FINS BY CIRCULAR PERFORATIONS" (IJAME) ISSN: 2229-8648 (Print); ISSN: 2180-1606 (Online); Volume 4, pp. 428-436, July-December 2011

[3] Osamah Raad Skheel Al-khafaji, Nizar F.O. Al-Muhsen, "ASSOCIATED EFFECT OF PERFORATIONPOSITION AND DIAMETER ON THERMALPERFORMANCE OF PLANE FIN UNDER NATURAL CONVECTION ENVIRONMENT" Published online 27 August 2020 82:5 (2020) 101–108| www.jurnalteknologi.utm.my | eISSN 2180–3722

[4] Maha A. Hussein, Vinous M. Hameed, "An implementation study on a heat sink with different fin configurations under natural convective conditions" Case Studies in Thermal Engineering 30 (2022) 101774

[5] Akhilesh Kumar Singh, Rajiv Varshney, "Experimental investigation on rectangular fins with holes in natural convection" © 2017 IJEDR | Volume 5, Issue 4 | ISSN: 2321-9939

[6] Basima S. Khalaf, Ahmed K. Muhammad, "Experimental and Numerical Investigation of Heat Transfer Enhancement Using Circular Perforated Finset" al 2020 IOP Conf. Ser.: Mater. Sci. Eng. 870 012168

[7] Rashin Nath. KK, Jayee K. Varghese, "Design Modification and Analysis of Two Wheeler Engine Cooling Fin" (IJERMCE) Vol 2, Issue 7, July 2017 ISSN (Online) 2456-1290

[8] Ashok Tukaram Pise, Umesh Vandeorao Awasarmol, "INVESTIGATION OF ENHANCEMENT OF NATURAL CONVECTION HEAT TRANSFER FROM ENGINE CYLINDER WITH PERMEABLE FINS" (IJMET), ISSN 0976 – 6359 (Online) Volume 1 Number 1, July - Aug (2010)

[9] Mahathir Mohammad, Md. Ponir Hossain Talukder, Kazi Afzalur Rahman, Monowar Wadud Hridoy, "EXPERIMENTAL INVESTIGATION ON THE EFFECT OF DIFFERENT PERFORATION GEOMETRY OF VERTICAL FINS UNDER FORCED CONVECTION HEAT TRANSFER" (ICMERE) 11–13 December, 2019

[10] G. M. Sobamowo, O. M. Kamiyo, M. O. Salami, A. A. Yinusa, "Exploration of the effects of fin geometry and material properties on thermal performance of convective-radiative moving fins" Vol. 2 (2019), Issue 3, pp. 14 – 29ISSN: 2617-9709 (Online)

[11] Abdullah, H. Al. and Mohammed Q. A., "Enhancement of natural convection heat transfer from a fin by triangular perforations of bases parallel and toward Its base", The Arabian Journal for Science and Engineering (2009) , 34(2B): 531-544.

[12] Al-Essa, A.H. and Al-Hussien, F.M.S. 2004, "The effect of orientation of square perforations on the heat transfer enhancement from a fin subjected to natural convection", Heat and Mass Transfer, 40: 509-515.

[13] Bayram, S. and Alparslan D., "Performance analysis of a heat exchanger having perforated square fins" Applied Thermal Engineering (2008), 6: 621-632.

[14] Chung, B.T.F. and Iyer, J.R., "Optimum design of longitudinal rectangular fins and cylindrical spines with variable heat transfer coefficient" Heat Transfer Engineering (1993), 14: 31-42.

[15] Elshafei, E.A.M., "Natural convection heat transfer from a heat sink with hollow/perforated circular pin fins" Energy (2010), 35: 2870-2877.

[16] Kutscher, C.F., "Heat exchange effectiveness and pressure drop for air flow through perforated plates with and without crosswind" Journal of Heat Transfer (1994), 116: 391-399.

[17] Bassam A/K Abu Hijleh, "Natural convection heat transfer from a cylinder with high conductivity permeable fins", ASME J. Heat Transfer, vol-125, Apr-2003

[18] Bogdan I. Povel, Abdulmajeed A. Mohamad, "An experimental and numerical study on heat transfer enhancement for gas heat exchangers fitted with porous media" International Journal of Heat and Mass Transfer 47 (2004), pp. 4939-4952

[19] Waleed Al-Salami, Amer Al-Damook, H.M. Thompson, "A Numerical Investigation of the Thermal-Hydraulic Characteristics of Perforated Plate-Fin Heat Sinks", International Journal of Thermal Sciences, 121 (2017) 266-277

[20] Karima Boukhadiaa, Houari Ameura, Djamel Sahelc, Mohamed Bozitb, "Effect of the Perforation Design on the Fluid Flow and Heat Transfer Characteristics of a Plate Fin Heat Exchanger", International Journal of Thermal Sciences, 126 (2018) 172–180.

[21] Kale S., Bhatkar V., "A Review of Electronic Equipments Cooling Through Rectangular Fin Array By Using Natural Convection", International Journal of Current Engineering and Scientific Research, Volume 2, Issue 2, 2015, pp.93-97.

[22] Samarth A., Kale N., "A Review of Thermal Analysis of Cylindrical Perforated Fins in Staggered Arrangement", International Journal of Research in Science and Engineering, Volume 1, Issue 6, pp. 80-88.

[23] Kanaskar A.A., Kriplani V.M., Walke P.V., "A Review of Heat Transfer Enhancement from Heat Sink Using Perforated Fins", Volume 3, Issue 6, 2015, ISSN No. 2309-4893, pp.726-730.

[24] Barhatte S. H., Chopade M. R., Kapatkar V. N., “Experimental and Computational Analysis And Optimization For Heat Transfer Through Fins With Different Types of Notch”, Journal of Engineering Research and Studies, vol.2, Issue 1, 2011, pp.133-138

[25] Ehteshum, Mehedi, et al., "Thermal and Hydraulic Performance Analysis of Rectangular Fin Arrays with Perforation Size and Number", Procedia Engineering 105, 2015, 184-191.

[26] Ismail, Md Farhad, et al., "NUMERICAL investigation of turbulent heat convection from solid and longitudinally perforated rectangular fins", Procedia Engineering 56, 2013, 497-502.

[27] M.R.Shaeri, M. Yaghoubi, "Numerical analysis of turbulent convection heat transfer from an array of perforated fins", International Journal of Heat and Fluid Flow, 2009, 218-228.

[28] Al-Damook, Amer, et al., "Computational design and optimisation of pin fin heat sinks with rectangular perforations", Applied Thermal Engineering, (2016)

[29] Noaman Salam, Khan Rahmatullah, Faizanurrahman, Salman Ah, Ansari Tohid, Tarique Khan, "Heat Transfer Enhancement Through Perforated Fin" IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684, p-ISSN: 2320-334X, PP. 72-78

[30] Mohamad I. Al-Widyan, Amjad Al-Shaarawi, "Numerical Investigation of Heat Transfer Enhancement for a Perforated Fin in Natural Convection", International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622, Vol. 2, Issue 1, pp.175-184