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REVIEW FOR EXPERIMENTAL AND NUMERICAL STUDY INVESTIGATED ON PERFORATED FIN HEAT SINKS

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ABSTRACT

This paper presents a comprehensive overview of the experimental and numerical simulation work performed over the plate and pin fin heat sinks. So far quite impressive work has been done to enhance the heat transfer from the surface which is under investigation. One of the important heat transfer augmentation technique which has been given major attention in this review paper, is making perforation of pin fins. Study on the shapes of various fin cross sections such as pin fin, plate fin, plate and pin fin, cubic shapes, elliptical fin, square fin, diamond shaped fin, NACA and dropform fin and rectangular strips, have been considered for this review paper. Further perforation of various shapes like circular, elliptical or square has been done in all these types of fin cross sections and positive results are found for the purpose of heat transfer augmentation. From the study of available literature, it has been concluded that perforation increases the average Nusselt number and decreases the fan power required for the flow past the heat sink. And these two parameters are very important for an effective heat exchanger. The numerical simulation work has been found in well agreement with the experimental work performed in respective field.

I. INTRODUCTION

Many industries like aerospace, automotive, nuclear and electronics have critical components which need to be cooled to avoid any serious over-heating problem. The rapid advancement in electronic industry has resulted an increase in heat flux with restriction on the component size. The increased heat flux has proportional effect on the increased component temperature which motivates the design of the cooling system so that temperature can be controlled within liable limit. Heat sinks with extended surface such as rectangular, circular, square, elliptic fins are widely used in industries to improve the heat transfer in critical cooling applications. It is important to design a heat sink by considering both the heat transfer and pressure drop characteristics.

II. HEAT TRANSFER AUGMENTATION

In general fins of various shapes of cross sections are being employed to remove the unwanted heat from the surface. By keeping in mind the various aspects like reduction in geometry complexity, flow restriction and limited surface temperature, we need some heat augmentation techniques. Perforation of fins may lead to a very good method of heat augmentation. Fluid flowing through the perforation will reduce the size of the wake behind the fin which will reduce the flow separation and hence pressure drop across the fin will reduce. The combined effect of increased contact surface area with perforation and localized fluid jet through the perforation, will contribute the larger fluid speed which will enhance the convective heat transfer. Perforation of suitable shape like circular, elliptical or square can help to achieve this target. Any type of fin cross section like pin fin, plate fin, plate and pin fin, cubic shapes, elliptical fin, square fin, diamond shaped fin, NACA and drop-form fin and rectangular strips, can be perforated. Heat transfer augmentation techniques can be classified into following three categories:

a) Active Method

This method need some external power input for the purpose of heat transfer augmentation. But this method is not generally used because of its complex design and cost concerns. Some generally used techniques in this category are: mechanical aid, surface vibration, fluid vibration, electrostatic field, injection, suction and jet impingement.

b) Passive Method

This method does not need any external power input for the purpose of heat transfer enhancement. In this method, heat transfer can be improved by increasing the heat exchange surface area, the physical properties of the surface and that of fluid can also be modified to improve the heat transfer. Some generally used techniques in this category are: treated surfaces, rough surfaces, extended surfaces, displaced enhancement devices, swirl flow devices, coiled tubes, surface tension devices, additives for liquids and gases.

c) Compound Method

This method of heat transfer augmentation is the combination of active and passive method simultaneously. This method has limited applications because it involves complex design.

III. LITERATURE REVIEW FOR PREVIOUS WORK

Yu et al. [1] have compared the performance of plate fin heat sink (PFHS) and the plate and pin fin heat sink (PPFHS). Here PPFHS is composed of plate fin heat sink and some columnar pins staggered in-between plate fins. Numerical simulations as well as experiments are performed for the purpose of comparison. From the study it has been concluded that the thermal resistance of PPFHS is 30 % lower than that of PFHS with the same air velocity since some columnar are planted in the flow passage of PFHS to disturb the air flow passing through the heat sink. Different cooling performances can be achieved by planting columnar pins with different number or different geometry parameters.

Jonsson and Moshfegh [2] have studied seven types of heat sinks including strip fin, plate fin and pin fin (having circular and square cross section) and each case has two categories of in-line and staggered arrays. An empirical correlation has been produced for the purpose of comparison of fins. The correlation predicts the Nusselt number and the dimensionless pressure drop and also takes into account the effect of duct height, width and fin height and thickness/diameter. From the study they have concluded that with increasing Reynolds number, the increase in pressure drop is larger in pin fin heat sinks and the decrease in thermal resistance is marginal. It has come out that use of pin fin heat sink at high Reynolds number is not beneficial. Further they have concluded that longer fins result in lower pressure drop, staggered array results in a larger pressure drop than an in-line array and circular fins have lower pressure drop as compared to square fins.

Nakamura et al. [3] have done the experimental work to investigate the fluid flow and local heat transfer around a cube mounted on a flat plate. A cube with height of 30 mm has been analysed inside a wind tunnel. The free stream velocity is kept in range of 2.2 to 17.3 m/s and corresponding Reynolds number is 4.2×10^3 to 3.3×10^4. It has been concluded that on the base wall, the local heat transfer is significantly high in region of horseshoe vortex formed in the front and both sides of cube. The Nusselt number on the front face is more than double that on the base wall away from the cube. The average Nusselt number on every face has been expressed as:

Front face: $\overline{Nu} = 0.71Re^{0.52}$

Side face: $\overline{Nu} = 0.12Re^{0.70}$

Rear face: $\overline{Nu} = 0.11Re^{0.67}$

Top face: $\overline{Nu} = 0.071Re^{0.74}$

And Overall Nusselt number: $\overline{Nu} = 0.138Re^{0.68}$.

Niceno et al. [4] have done the numerical investigation to study the internally heated multi-layered matrix of cubes mounted on one of the walls. The problem is solved by Large Eddy Simulation (LES). The study is considered to be relevant with the cooling of electronic components on circuit board or cooling of gas turbine blades through internal passage equipped with pins or ribs. From the paper it has been concluded that the flow impingement on the front face and the flow separation from the sharp edges of the cube enhanced the heat transfer, while the detected recirculation zone prevents beneficial cooling. It has been found that highest temperature occurs at the rear wall of the cube, due to present of arch-shaped vortex. The average heat transfer coefficient on the front face is found to be 24% higher and on the rear face it is 23 % lower than the cube averaged value.

Sayed et al. [5] has done the experimental study to find the heat transfer, fluid flow and pressure drop characteristics of longitudinal rectangular fin array for three orientations like 1) parallel flow 2) impinging flow and 3) reverse impinging flow. From the study it has been concluded that in the core region the fin mean Nusselt number for the parallel flow case is greater than that for the other two cases. While for the terminal region, the fin mean Nusselt number for the impinging flow case has the greatest value followed by the parallel flow case then the reverse impinging flow case.

Velayati and Yaghoubi [6] have done the numerical study of convective heat transfer from an array of parallel bluff plates. This investigation has considered the effect of variation of fin blockage ratio and flow Reynolds number. These parameters have been changed to get their effect on reattachment position, pressure distribution, velocity vector field, friction coefficient and overall Nusselt number along the block surface. From the study it has been concluded that the separation and reattachment over the plate surface and recirculation downstream of the plate are highly dependent on Reynolds number and plate blockage ratio. The average friction factor coefficient decreases with increasing Reynolds number and effect is very similar to the flow over flat plate. Also the friction coefficient increases with increasing blockage ratio. The average Nusselt number increases with increasing Reynolds number and blockage ratio.

Zhou and Catton [7] have numerically evaluated the 20 different plate-pin fin heat sinks with various pin cross sections (circular, square, elliptic, NACA profile and dropform). A finite volume method based ANSYS CFX CFD software is used as 3D Reynolds Averaged Navier-Stokes solver. A k-ω based SST model is used to solve the turbulent flow through the heat sink channel. Among plate-pin fin heat sinks, square type PPFHS has highest Nusselt Number as well as highest pressure drop which leads to lower overall performance. Further they have concluded that streamline shaped types of PPFHS have much better performance than circular and square type PPFHS. And among these streamline shapes, the elliptic and NACA type PPFHS have similar overall performance with elliptic type overweighing the NACA type PPFHS followed by the dropform type PPFHS.

Yuan et al. [8] have also studied the plate pin fin heat sink using numerical analysis. The aim of the study is to find the key parameters which influence the hydraulic and thermal performance of PPFHS. Here they have studied four types of PPFHS with different pin diameter combinations. The simulation results are found to agree with available experimental results. From the study it has been concluded that with the increase in Reynolds number the flow resistance will increase and the thermal resistance and profit factor will decrease significantly. For the safe working of electronic stuff, the maximum surface temperature has to be no more than 85º C (358 K). Here the heating power has been optimized with maximum limit of 60 W, beyond this limit the surface temperature will cross its safe working limit of 85º C.

Sara et al. [9] have experimentally get the thermal performance for solid and perforated blocks attached on a flat surface in a duct flow. This performance was compared with the same plate without blocks. Flow and the geometry conditions are kept as main parameter for the purpose of analysis. The main performance criteria for the purpose of comparison is heat transfer enhancement efficiency (η) which is defined as the ratio of convective heat transfer coefficient with and without blocks. From the study it has been concluded that the solid blocks enhance the heat transfer from the plate significantly as a result of increased heat transfer surface area, lead high pressure drop in the flow and they generate a net energy loss. But when the blocks are perforated, the net energy loss is recovered. For both of the cases, with increase in Reynolds number, the performance decreases. In case of perforated blocks, the higher the perforated diameter, perforated area and inclination of the perforation holes towards plate surface, the heat transfer enhancement performance comes out better.

Sahin and Demir [10] have done experimental work for the performance analysis of heat exchanger having perforated pin fins. Various cases have been studied by using Reynolds number range 13500-42000, clearance ratio of 0, 0.33 and 1 and inter-fin spacing ratio of 1.208, 1.524, 1.944 and 3.417. The Nusselt number and friction factor has been considered as performance parameters. From this experimental work it has been concluded that the Nusselt number increases with decreasing clearance ratio and inter-fin spacing ratio. The friction factor increases by increasing clearance ratio and inter-fin spacing. The enhancement efficiency has been found to increase with decreasing Reynolds number. The maximum heat transfer was found at 42000 Reynolds number, 75mm fin height and 3.417 inter-fin spacing.

Sahin and Demir [11] have also studied the performance analysis of a heat exchanger having perforated square fins. Various cases have been studied by using Reynolds number range 13500-42000, clearance ratio of 0, 0.33, and 1 and inter-fin spacing ratio of 1.208, 1.524, 1.944 and 3.417. The fin used in this paper has square cross section of $15\ \text{mm} \times 15\ \text{mm}$ and were fixed at the upper surface of base plate. The perforation was done at 17 mm from the bottom surface by 8 mm diameter drill bit. It has been concluded that the Nusselt number increases with decreasing clearance ratio and inter-fin spacing ratio. The friction factor increases by increasing clearance ratio and inter-fin spacing. The enhancement efficiency has been found to increase with decreasing Reynolds number. The maximum heat transfer was found at 42000 Reynolds number, 50 mm fin height and 3.417 inter-fin spacing.

Shaeri and Yaghoubi [12] have done the numerical analysis of turbulent forced convection heat transfer from an array of perforated fins. The aim of this study is to achieve the thermal performance of perforated fins and comparing these results with that of solid fins. The solid fin comprises of a rectangular plate of length, height and thickness equal to 24, 12 and 4 mm respectively. Fin spacing is fixed as 10 mm. From the study it has been concluded that at higher Reynolds number, the flow around the solid fin and 1 perforated fin is unsteady while by increasing the number of perforation, the flow is found to be steady at same Reynolds number. The most important conclusion has come out that the perforated fin has higher fin effectiveness than that of solid fin.

Sparrow and Grannis [13] have done experimental and numerical simulation to determine the pressure drop characteristic of array of diamond shaped pin fins. Two diamond shaped fin geometries were analysed, one with 45º vertex angle and other with 90º vertex angle. The diamond shaped fin width has been fixed as W=0.3175 cm and corresponding axial length L for 45º and 90 ºvertex angle fins is 0.7621 cm and 0.3175 cm. Height has been kept as 24W i.e. H= 7.621 cm. Reynolds number range has been kept as 20 – 2200. From the study it has been concluded that the pressure distribution for 45º fin array has become fully developed after just one row in array and for 90º fin, the fully developed pressure distribution is not attained until five or six rows in array.

Damook et al. [14] have numerically and experimentally investigated the pin fin heat sinks. They have found that the performance of Pin fin heat sink can be improved by doing the perforation of pin fin. The experimental setup consists of two heat sinks, the first with solid Fins and second with perforated fins. The fins have 2 mm diameter and 10 mm length. A constant heat flux of 20000 w/m^2 is provided at the bottom of heat sink. For the purpose of numerical analysis, a computational domain having only one flow passage with symmetry boundary conditions, has been investigated. From the study they have concluded that the circular perforation of fins has monotonically increased the Nussselt number while the pressure drop and corresponding fan power has been reduced monotonically.

Damook et al. [15] have further extended their previous work and have studied the rectangular notched and slotted pin perforation. From this study they have concluded that fin performance can be improved by using the rectangular notched perforation. Further they have found that in comparison to circular perforation, the rectangular perforation depicts better results.

Damook et al. [16] In extension of their research work have numerically compared the effect of various perforation shapes (circular, square and elliptic) on perforated pin fin heat sinks. A conjugate heat transfer analysis with RANS-based k-ω turbulence model has been used for the numerical study. From the study they have concluded that among these perforation shapes, the circular perforation provides the highest Nusselt number because they maximize the speed of air flowing through the perforation and the elliptic perforation provide the highest reduction in pressure drop since they minimize the resistance to air flowing through the perforation.

IV. CONCLUSION

The study of available literature on the topic of flow and heat transfer through plate and pin fin heat sinks, has make out the following conclusions:

- The thermal and hydraulic performance of plate & pin fin heat sink (PPFHS) is better than plate fin heat Sink (PFHS), keeping all other flow parameters same.
- From the various shapes of fin cross sections like circular, square, elliptic, NACA profile and dropform, it has been concluded that the streamline shaped fins like elliptical and NACA fins perform better as compared to other cases.
- Circular perforation of fins has monotonically increased the Nussselt number while the pressure drop and corresponding fan power has been reduced monotonically.
- In comparison to circular perforation, the rectangular perforation depicts better results.
- Among the circular, elliptical and square shaped perforation, the circular perforation provides the highest Nusselt number and the elliptic perforation provide the highest reduction in pressure drop.

REFFERENCES

[1] X. Yu, J. Feng, Q. Feng, and Q. Wang, "Development of a plate-pin fin heat sink and its performance comparisons with a plate fin heat sink," *Appl. Therm. Eng.*, vol. 25, no. 2–3, pp. 173–182, 2005.

[2] H. Jonsson and B. Moshfegh, "Modeling of the thermal and hydraulic performance of plate fin, strip fin, and pin fin heat sinks - Influence of flow bypass," *IEEE Trans. Components Packag. Technol.*, vol. 24, no. 2, pp. 142–149, 2001.

[3] H. Nakamura, T. Igarashi, and T. Tsutsui, "Local Heat Transfer around a Wall-Mounted Cube in the turbulent boundary layer," *Trans. Japan Soc. Mech. Eng. Ser. B*, vol. 65, pp. 3105–3110, 1999.

[4] B. Niceeno, A. D. T. Dronkers, and K. Hanjalic, "Turbulent heat transfer from a multi-layered wall-

mounted cube matrix: A large eddy simulation," *Int. J. Heat Fluid Flow*, vol. 23, no. 2, pp. 173–185, 2002.

[5] S. A. El-Sayed, S. M. Mohamed, A. A. Abdel-Latif, and A. H. E. Abouda, "Experimental study of heat transfer and fluid flow in longitudinal rectangular-fin array located in different orientations in fluid flow," *Exp. Therm. Fluid Sci.*, vol. 29, no. 1, pp. 113–128, 2004.

[6] E. Velayati and M. Yaghoubi, "Numerical study of convective heat transfer from an array of parallel bluff plates," vol. 26, pp. 80–91, 2005.

[7] F. Zhou and I. Catton, "Numerical Evaluation of Flow and Heat Transfer in Plate-Pin Fin Heat Sinks with Various Pin Cross-Sections," *Numer. Heat Transf. Part A Appl.*, vol. 60, no. 2, pp. 107–128, 2011.

[8] W. Yuan, J. Zhao, C. P. Tso, T. Wu, W. Liu, and T. Ming, "Numerical simulation of the thermal hydraulic performance of a plate pin fin heat sink," *Appl. Therm. Eng.*, vol. 48, pp. 81–88, 2012.

[9] O. N. Sara, T. Pekdemir, S. Yapici, and H. Erşahan, "Thermal performance analysis for solid and perforated blocks attached on a flat surface in duct flow," *Energy Convers. Manag.*, vol. 41, no. 10, pp. 1019–1028, 2000.

[10] B. Sahin and A. Demir, "Thermal performance analysis and optimum design parameters of heat exchanger having perforated pin fins," *Energy Convers. Manag.*, vol. 49, no. 6, pp. 1684–1695, 2008.

[11] B. Sahin and A. Demir, "Performance analysis of a heat exchanger having perforated square fins," *Appl. Therm. Eng.*, vol. 28, no. 5–6, pp. 621–632, 2008.

[12] M. R. Shaeri and M. Yaghoubi, "Numerical analysis of turbulent convection heat transfer from an array of perforated fins," *Int. J. Heat Fluid Flow*, vol. 30, no. 2, pp. 218–228, 2009.

[13] E. M. Sparrow and V. B. Grannis, "Pressure drop characteristics of heat exchangers consisting of arrays of diamond-shaped pin fins," *Int. J. Heat Mass Transf.*, vol. 34, no. 3, pp. 589–600, 1991.

[14] A. Al-Damook, N. Kapur, J. L. Summers, and H. M. Thompson, "An experimental and computational investigation of thermal air flows through perforated pin heat sinks," *Appl. Therm. Eng.*, vol. 89, pp. 365–376, 2015.

[15] A. Al-Damook, N. Kapur, J. L. Summers, and H. M. Thompson, "Computational design and optimisation of pin fin heat sinks with rectangular perforations," *Appl. Therm. Eng.*, vol. 105, pp. 691–703, 2016.

[16] A. Al-Damook, J. L. Summers, N. Kapur, and H. Thompson, "Effect of Different Perforations Shapes on the Thermal-hydraulic Performance of Perforated Pinned Heat Sinks," *J. Multidiscip. Eng. Sci. Technol.*, vol. 3, no. 4, pp. 4466–4474, 2016.