CHAPTER-2

LITERATURE REVIEW AND SCOPE OF WORK

2.1 INTRODUCTION

Literature on PFHS, Pin Fin, PFPFHS, and modified PFHS arrays under natural convection is reviewed in this chapter. Review of literature on PFHS arrays and pin fin heat sink arrays is given in Section 2.2.1 and 2.2.2 respectively. PFPFHS array is a modified PFHS array and literature available on it under forced convection condition is reviewed in Section 2.2.3. Review of modified PFHS array is given in Section 2.2.4. The conclusions of literature review are given in Section 2.3 and the problem under consideration is discussed in Section 2.4.

Needs for buoyancy driven ventilation appear in a variety of engineering applications, ranging from cooling of electronic components and solar energy applications to cooling of nuclear reactor fuel elements. For an efficient use of natural convection to cooling processes it is necessary to fully understand the mechanisms involved. In the free-convection cooling of electronic and thermoelectric devices, as well as in improving the heat transfer in radiators for air conditioning and in other heat exchangers, finned surfaces are being extensively used. Compared to a bare plate, a finned surface increases the heat transfer area. However, with the fins the fluid flow rate is reduced. Hence, if not properly designed it is possible that no improvement is achieved in terms of overall heat transfer. Therefore, only if the fins are properly designed, they are very attractive for these applications since they offer an economical, trouble-free solution to the problem. In spite of the fact that the heat transfer from fins has been the subject to numerous experimental and theoretical investigations, a few systematic parametric studies are found in the literature.

The nomenclature as used by the researcher is used in the following literature review.
2.2 REVIEW OF LITERATURE

2.2.1 Investigation of PFHS Arrays on Horizontal Base

The problem of rectangular fin arrays on horizontal base has been studied both analytically and experimentally. The analytical study includes both two-dimensional and three-dimensional models. Some of the experimental investigations incorporate flow visualization studies using simple smoke technique, Schlieren shadowgraph technique and Mach-Zehnder interferometric technique.

In very first studies, Elenbass [4] reported an experimental study on heat dissipation of parallel plates by free convection over a wide range of Rayleigh numbers. It was observed that in the limit of small gap width, Nusselt number varies proportional to the channel Rayleigh number.

Starner and McManus [5] determined average heat transfer coefficients for four fin arrays positioned with base vertical, at 45° and horizontal. It was found that vertical arrays performed 10 to 30% below the similarly placed parallel plates. The arrays at 45° performed 5 to 20% below the vertical arrays and performance of horizontal fin arrays was the lowest. Flow visualization tests were conducted using smoke technique. Vertical arrays and arrays at 45° showed predominant flow in the vertical direction with some inflow from the front of the fin channel. In addition to the above-mentioned flow patterns, for horizontal arrays a single chimney flow pattern was observed when the ends were kept open and down and up flow pattern when the ends were closed.

Harahap and McManus [6] extended the work of Starner and McManus [5] with an objective of more fully investigating the horizontal fin arrays. With a view to obtain pertinent dimensionless parameters the governing equations of continuity, momentum and energy were examined on the basis of similarity and a correlation was proposed in the following form:

\[
\text{Nu}_{L/2} = C \left( S^+ \text{Gr}_{L/2} \text{Pr N} \right)^a \left( S^+_{L/2} \right)^b \left( H^+_{L/2} \right)^c
\] ---- (2.1)

Where C, a, b and c are constants. This correlation fitted well with the data of both the investigations. Flow patterns were visualized and the flow pattern with a dominating end flow present in lengthwise shorter arrays was named as “a single chimney flow pattern”.
For relatively long arrays “a down and up fluctuating” flow was observed. For moderate lengths the third flow pattern was observed, wherein the single chimney broke into several smaller chimneys sliding back and forth along the longitudinal direction and was identified as “a sliding chimney flow pattern”. Harahap and Setio [7] proposed correlations for heat dissipation and natural convection heat transfer from horizontally based, vertically finned arrays.

Jones and Smith [8] undertook their investigation with the prime objective of establishing the optimum spacing of fins for maximum heat transfer from a given base surface. They experimentally determined average heat transfer coefficients for horizontal arrays over a wide range of spacing. Zehnder-Mach interferometer was used to find the local temperature gradients, which in turn were, used for calculation of heat transfer coefficients. The advantage of interferometric technique is that the heat transfer coefficients determined are for convection only and are independent of radiation. A simplified correlation for average heat transfer coefficient for all the arrays tested was suggested as given below,

\[ \text{Nu}_s = 6.7 \times 10^{-4} \text{Ra}_s [1- \exp(-0.746 \times 10^{-4}/\text{Ra}_s^{0.44})]^{1.7} \]  

---(2.2)

The data of Starner and Mcmanus [5] were in fairly good agreement with the above correlation. The following important findings are reported:

i. For the given fin height, length and \( \Delta T \), an optimum fin spacing exists for which the heat transfer rate is maximum.

ii. The average heat transfer coefficient increases with spacing and asymptotically approaches the flat plate value for large spacing.

Mannan [9] studied the effect of almost all pertinent geometrical parameters of the fin array on its performance. His work covered wide range of length: 12.7 cm < L < 50.8 cm, Height 2.54 cm < H < 10.16 cm and spacing 0.48 cm < S < 2.86 cm, with \( \Delta T \) varying from 39° C to 156° C. However, he could not solve the problem analytically due to the complex three-dimensional nature of the problem. He suggested the following correlation for finding out the average Nusselt number

\[ \text{Nu} = C_0 \text{Ra}_s^{C_1} \text{SL}^{4C_2} S^{4C_3} \]  

---(2.3)
The data of Harahap and McManus [6] and Jones and Smith [8] fit in the correlation reasonably well. Some important conclusions of Mannan are:

i. The fin spacing is most important geometrical parameter and for a given height, length and temperature difference, an optimum spacing exists for which the heat transfer rate is maximum. The optimum spacing is given by,

\[ S_{\text{opt}} = 0.332 L^{0.177} H^{-0.0266} \left( \frac{Q}{A_b \Delta T} \right)^{-0.192} \]  

\[ ----(2.4) \]

Where \( S_{\text{opt}}, L \) and \( H \) are in inches and \( \left( \frac{Q}{A_b \Delta T} \right) \) in Btu / hr-ft\(^2\)-\(^\circ\)F

ii. The fin length is another important geometrical parameter. Short fin arrays perform better than long arrays, due to prevailing single chimney flow pattern up to \( L^+ < 5 \).


Sane and Sukhatme [13] investigated the problem of horizontal fin array. They solved the governing equations neglecting the velocity component normal to the fin flats in the case of single chimney flow problem and employing vorticity – stream function formulation. A finite difference scheme and an iterative numerical procedure were used. The results were obtained for \( 10^5 < Gr_H < 10^7, 2 < L^+ < 8 \) and \( 0.0625 < S^+ < 0.5 \), in case of single chimney flow problem. Beyond certain values of \( S^+ \) on lower side, the single chimney flow pattern ceases to exist due to choking effect on the entering side flow. They also carried out flow visualization studies using Schlieren apparatus and proved that the point of maximum heat transfer lies at the transition from single chimney flow pattern to sliding chimney and the corresponding \( S^+ \) becomes the optimum spacing. The following correlation was proposed:

\[ Nu_{bH} = 0.45 Gr_H^{0.96} S^{-0.57} L^{-0.99} \]  

\[ ----(2.5) \]

Shalaby [14] investigated laminar natural convection from vertical and horizontal fin arrays. He solved the problem without neglecting the velocity components perpendicular to the fin flats. This involves the solution of the full set of Navier-Stokes equations,
governing the three components of velocity, pressure and temperature each being a function of three space co-ordinates. The situation of the horizontal and vertical fin array is analyzed. The analytical solution of this problem required the simultaneous solution of the 3D equations of continuity, momentum and energy. These were converted in their dimensionless form. The finite difference formulation used for solving square cavity problem was derived using the 3D analogue of the formulation. The grid spacing in X and Z directions was uniform within the fin area and expanded in a geometric series in the extended domain. The grid spacing in the Y direction was uniform. The resulting set of finite difference equations was solved iteratively, using the three-dimensional ADI scheme. The results were obtained over a range of dimensionless parameters $10^5 < \text{Gr} < 10^7$, $S^+ = 0.125, 0.25, 0.375$ and 0.5 and $L^+ = 2, 4$ and 8 for $Pr = 0.7$ and presented in terms of velocity distributions, temperature profiles and average and base Nusselt numbers.

Karagiozis [15] investigated laminar, free convection heat transfer from isothermal finned surfaces and confirmed the findings of Shalaby [14].

Patil et al. [16] carried out a preliminary investigation of the problem of three-dimensional analysis of horizontal rectangular fin arrays under natural convection conditions. They employed a 3D-3D finite difference scheme similar to that of Shalaby et al. [14] with some modifications.

The data was generated for $L / H = 0.5, 0.25$ and 0.125, $S / H = 0.125, 0.25, 0.375$ and 0.5, $\text{Gr}_H = 10^4, 10^5, 10^6, \text{and } 10^7$ and $Pr = 0.7$.

Yuncu and Anbar [17] reported an experimental study of free convection heat transfer from rectangular fin-arrays on a horizontal base. The experiments were conducted so as to clearly identify the separate roles of fin height, fin spacing and base-to-ambient temperature difference. The prime objective of this study was the prediction of optimum fin spacing for maximum heat transfer as a function of fin height and base-to-ambient temperature difference.

Rao et al. [18] carried out experimental investigation of interaction of free convection and radiation in a horizontal fin array. They used a differential interferometer
to obtain free convection heat transfer and numerically solved the integro-differential equations to calculate radiation. The main conclusion drawn was to reconsider the additive approaches in which the radiation and convection contributions are independently calculated.

Dayan et al. [19] conducted a combined analytical, numerical and experimental study to investigate the problem of natural convection underneath a horizontal rectangular plate fin array. The analytical solution clearly reveals the dependence of Nu on the Ra, Pr and the fin’s height to spacing ratio. Optimum analyses were conducted to determine the minimum fin height that provides the necessary cooling capability of a specified array base area. It was shown that the optimal fin spacing varies within a narrow range which depends primarily on the array length. These findings have important industrial application because they impact both the cost and size of cooling finned surfaces.

Vollaro et al. [20] and Anand et al. [21] have reported a simple model to calculate the heat transfer of vertical finned surfaces in natural convection. Neglecting temperature variations and end effects in the vertical direction as well as without taking into account the temperature dependence of the fluid properties, the effect of the thermal conductivity and of the emissivity of the fins material and of the heat exchanged by the unfinned portion of the base plate on the optimum performance of the system have been evaluated. The main effect of finite fin conductivity is a reduction of the optimal fins spacing; taking into account this possibility of compacting the system, the heat flux can be increased by as much as 20%.

Sobhan et al. [22, 23] investigated experimentally free convection heat transfer from fins and fin arrays attached to a heated horizontal base. They used the technique of differential interferometry. The major difference between the single fin case and the array case is encountered near the fin tip. The fin array shows an abrupt increase in the values in this region. It is also reported that the optimum spacing of fin arrays is material dependent. It is shown that the combination of aluminum and 10 mm spacing gives the maximum value of \( q_{\text{total}} / \text{mm of base} \).
Baskaya et al. [24] carried out parametric study of natural convection heat transfer from the horizontal rectangular fin arrays. They investigated the effects of a wide range of geometrical parameters like fin spacing, fin height, fin length and temperature difference between fin and surroundings; to the heat transfer from horizontal fin arrays. An infinite number of fins with negligible thickness were assumed. The fin surfaces and fin array base were assumed to be at a uniform temperature. Radiation heat loss was neglected. The computational domain was reduced to one quarter of one fin channel with an extension towards one open end, in agreement with the geometry and symmetry conditions of the problem. They observed the single chimney type flow pattern in which chimney is only a fraction of the width of the fin array. According to them, on the overall, the heat transfer coefficient values increased with increase in the fin height. A small drop with increase in the fin height was observed for the smallest fin spacing. However, no clear conclusions were drawn due to the various parameters involved.

2.2.2 Investigation of Pin Fin Arrays

Pin fins are used to increase heat transfer from heated surface to air. Industrial experience shows that for the same surface area, pin fins can transfer considerably more energy than plate fins. The analysis of single pin is well known. However, when the pins are placed in an array, the convective patterns become more interrelated. Pin fin arrays on horizontal and vertical base have been studied by various investigators, analytically and experimentally. Studies on orientation effect and different shapes have also been undertaken.

Haldar [25] investigated numerically free convection about a single circular fin on a horizontal base plate. Fluid is drawn towards the fin from the far field which cools the fin and finally leaves through the top. For short fins, convection rather than the conduction is the controlling mode and this renders the fin thermal conductivity a parameter of little importance for such fins. Heat flux at the base of the fin decreases with increase in fin diameter confirming the benefits of large number of thinner fins. The upper bound of rate of heat transfer from any horizontal heat sink with circular pin elements may be determined with the use of the correlation developed in the investigation. Comparison of heat transfer so calculated for a heat sink with the recently
published results indicates that the percentage difference between the two results decreases with increasing plate temperature.

Sparrow et al. [26] investigated experimentally the heat transfer characteristics of highly populated pin-fin arrays for three different orientations in the gravity field: (1) horizontal fins and vertical base plate, (2) vertical fins and horizontal down facing base plate, and (3) vertical fins and horizontal up facing base plate. Experiments were performed in air to measure the combined natural convection and radiation heat transfer, and the radiation was determined analytically. Parametric variations were also made of the number of fins and of the base plate-to-ambient temperature difference. In general, among the three orientations, the vertical up facing fin array yielded the highest heat transfer rates, followed by the horizontal fin array and the vertical down facing fin array. With an increase in the number of fins for fixed values of the other parameters, the heat transfer rate increased at first, attained a maximum, and then decreased, thereby defining an optimal fin population. The fractional contributions of radiation to the combined-mode heat transfer were generally in the 25-40% range, with the larger contributions occurring at the smaller base plate-to-ambient temperature differences. Comparison of the pin-fin results with those for plate fins tends to encourage the use of pin fins.

Sparrow et al. [27] investigated experimentally the combined-mode natural convection/radiation heat transfer characteristics of highly populated pin fin arrays. The fins were oriented with their axes horizontal and were attached to a vertical heated base plate. The investigated parameters included the number of fins in the array, the fin length and diameter, the base plate-to-ambient temperature difference. Finning was found to be highly enhancing, and even the longest fins were highly efficient. When the number of fins was increased for fixed values of the other parameters, the heat transfer increased at first, attained a maximum, and then decreased. Arrays having different diameter fins yielded about the same performance when the surface area of the fin-base plate assembly was held fixed. Calculations showed that the contribution of radiation was substantial and was greatest for more populous arrays, for longer fins, and at small temperature differences.
Sahray et al. [28] studied heat transfer from horizontal-base pin fin heat sinks in free convection of air. Heat-transfer enhancement due to the fins is assessed quantitatively and analyzed for various base sizes and fin heights. The effect of fin location in the array on its contribution to the heat-transfer rate from the sink was analyzed. A correlation that encompasses all the cases studied herein was obtained, in which the Nusselt number depends on the Rayleigh number, which uses the spacing between fins as the characteristic length, and on the dimensions of the fins and the base. The correlation makes it possible to design horizontal-base pin-fin heat-sinks in a broad range of base sizes, fin heights, and fin population densities.

Aihara et al. [29] experimentally investigated free convective and radiative heat transfer from dense pin fin arrays with a vertical isothermal base plate. The free convective heat transfer characteristics of pin-fin arrays are correlated with Nusselt number, Rayleigh number, based on the horizontal spacing of vertical pin arrays as a characteristic length. They found that the generalized characteristics are similar to those of rectangular fin arrays.

Zografos et al. [30] studied three types of arrays employing different values of D/W ratio, for fixed base plate and fin length. The conclusions of the study are as follows.

i) The most important geometric affecting the convective performance of a pin-fin array is the ratio of pin fin diameter to spacing, D/P. The heat transfer coefficient decreases with D/P increasing over 1/3.

ii) Inclination does not have a significant effect on heat transfer.

iii) When the array is under uniform heating conditions, its lower portions exhibit higher heat transfer coefficients than upper portions.

iv) Inline array yields higher heat transfer rates than staggered arrays, the rate decreases with increasing D/P.

Sertkaya et al. [31] experimentally investigated the effects of orientation angle on heat transfer performance of pin-finned surfaces in natural convection by considering the radiation heat transfer from the surfaces. The effects of orientation angle of base plates are analyzed for the cases of either the pins are facing upwards or downwards. The results show that, both the rates of heat transfer and the pin effectiveness are higher when the
pins are facing upwards. Heat transfer rate is maximum for the case when base plates are vertical and therefore the pins are horizontal. The rates of heat transfer and pin effectiveness are decreasing with increasing orientation angle and this is more sensed when the pins are facing downwards.

Ren-tsung Huang et al. [32] examined the heat transfer characteristics of square pin fin heat sinks subject to the influence of orientation under natural convection in the present study. The study reports following conclusions:

i) Generally, the downward facing orientation yields the lowest heat transfer coefficient. However, the heat transfer coefficients for upward and sideward facing orientations are of comparable magnitude. It is found that the performance of sideward arrangement exhibits a greater dependence on fin structure. The sideward arrangement outperforms the upward one for small fining factors, beyond which the situation is reversed.

ii) The performance of sideward arrangement may be superior or inferior to that of upward arrangement by 20%. In addition, with a gradual increase in fining factor, the performance of sideward arrangement approaches that of downward arrangement.

iii) The pin fin arrays in the present study outperform the flat plate on the thermal performance by 1.1–2.5 times for upward arrangement, by 0.8–1.8 times for sideward arrangement, and by 1.2–3.2 times for downward arrangement. It is found that fining is comparatively more effective for downward arrangement and is less effective for sideward arrangement.

Sahiti et al. [33] presented the work which was aimed for the demonstration of a simple and practical procedure for selection and optimization of the pin cross-section for electronics cooling. The selection of the best pin cross-sections was performed. The optimization of the elliptical cross-section was performed using the commercial optimization software.

Heat transfer by free convection and radiation from horizontal base pin-fin heat sinks, exposed to ambient at their perimeters, has been studied experimentally and
The effects of fin height and fin population density on the performance of the sinks have been investigated at various heat inputs. It has been found that the heat-transfer enhancement by the fins increases up to a certain fin population density, and then decreases, demonstrating an optimum array at various fin heights. The results also show that in horizontal-base pin-fin heat sinks the outer rows, which are exposed to free flow of ambient air, contribute the major part of the total heat transfer to the surroundings. Moreover, an individual outer-row fin contributes much more than an inner fin. The free convection contribution to the combined heat transfer has been decoupled from that of radiation, and generalization of the results has been achieved for all cases explored in the work. This generalization is based on the Rayleigh and Nusselt numbers, defined for the “clear” spacing between the fins as the characteristic length. The fin width-to-height ratio serves as an additional dimensionless parameter. The results of the study contributed to the optimal design of pin-fin heat sinks in natural convection and radiation. They also serve as a basis for a broader study, in which the effects of base dimensions are being explored in the context of sink scaleup.

Sahray et al. [35] studied heat transfer by free convection and radiation from horizontal base pin-fin heat-sinks experimentally and numerically. Sinks had various fin population densities, fin heights, and base sizes. The study was focused on the effect of base size, thus aiming at the generalization of free convection attempted earlier [34]. In order to obtain generalization, heat-sinks with free and blocked edges were studied. The heat-sinks with blocked edges were used to model large sinks, which are less affected by their perimeter. It was demonstrated that, indeed, when the edges are blocked, air flow to the sink changes. Rather than moving from the edges to the center and up, it is characterized by multiple inflows from above, as expected when the base is very large. Generalization of the results for free convection, decoupled from radiation contribution, has been achieved for all cases explored in the work, based on the Rayleigh and Nusselt numbers, defined for the “clear” spacing between the fins as the characteristic length, and the geometrical parameters of the sink. A correlation of the results, suggested in this study, makes it possible to design horizontal-base pin-fin heat-sinks in a broad range of base sizes, fin heights, and fin population densities.
2.2.3 Investigation of Plate Fin Pin Fin Arrays under Forced Convection

Xiaoling Yu et al. et al. [36] constructed a new type of plate and pin fin heat sink (PFPPFHS), which was composed of a PFHS and some columnar pins installed between plate fins. Numerical simulations and some experiments were performed to compare thermal performances of these two types of heat sinks under forced convection conditions. The simulation results showed that thermal resistance of a PFPPFHS was lower than that of a PFHS and results in better performance. The other findings of the study are:

i) Proposed a special solution for improving heat transfer performance of a PFHS by planting some columnar pin fins into flow passages of the PFHS to disturb airflow passing through the heat sink. So a PFPPFHS was constructed.

ii) Numerical simulation and experimental results show that the thermal resistance of a PFPPFHS was 30% lower than that of a PFHS used to construct the PFPPFHS with the same blowing velocity, and the profit factor of the former was about 20% higher than that of the latter with the same pumping power.

iii) Users can get various forms of PFPPFHSs by themselves from an existing PFHS through planting columnar pins with different numbers or different geometry parameters, and so get various PFPPFHSs with different cooling performances for their special requirements. The schematic diagram of a PFHS and PFPPFHS is shown in Fig. 2.1 and experimental and simulation results of variation of thermal resistance with wind velocity are shown in Fig. 2.2

Yue-Tzu Yang et al. [37] presented study on numerical computations of the PFPPFHS which provides physical insight into the flow and heat transfer characteristics. The purpose of the study was to examine the effects of the configurations of the pin-fins design and to examine the thermal and hydraulic performance of the PFHS and the PFPPFHS. The results showed that the PFPPFHS has better synthetical performance than the PFHS. In this study, the numerical simulations of PFPPFHS at various wind velocity and the configurations of pin-fins design were proposed. The results showed that increasing wind velocity could reduce the thermal resistance and increase the pressure drop simultaneously. The thermal resistance of the PFPPFHS was lower than that of the PFHS at the same wind velocity and the pressure drop of the PFPPFHS was much higher.
Fig. 2.1 Schematic diagrams of heat sinks: (a) plate fin heat sink; (b) plate-pin fin heat sink [36]

![Schematic diagrams of heat sinks](image)

Fig. 2.2. Variation of thermal resistance with wind velocity [36]

![Variation of thermal resistance with wind velocity](image)

Fig.2.2. Variation of thermal resistance with wind velocity [36]
than that of the PFHS. However, the synthetical performance of the PFPFHS was superior to the PFHS. And the synthetical performance of the mixed-height pins of the PFPFHS was better than the other case. Moreover, the results also showed that the synthetical performance of the in-line design was superior to the staggered design.

2.2.4 Investigation of Modified Plate Fin Arrays

As reported by earlier investigations, a horizontal array with single chimney flow pattern is preferred from heat transfer standpoint. It was envisaged by Gawali et al. [38] that a cross fin if added at the center of horizontal array, may enhance the flow in single chimney and may result in better performance. Some simple flow visualization experiments, using smoke technique supported the prediction. Preliminary work of 3D-2D problem with cross fin was reported in this paper. The main findings are:

i. The cross fin augments the flow in lengthwise short arrays.

ii. Arrays with cross fin perform better in terms of base Nusselt number.

iii. The flow augmentation may alter with the height of the cross fin.

Comprehensive findings, reported by Tikekar [39] for PFHSs with cross fin at the centre are as follows:

i. The values of cross component of velocity normal to the fin flat were generally small. The effect of cross component of velocity on the heat transfer coefficient and fluid flow characteristics was significant for longer fin arrays.

ii. An up flow of heated air was clearly seen in the U velocity plot. Velocity values increased in the upward direction.

iii. The W-velocity profile showed an incoming flow of cold air from the end of the fin array and decrease in the velocity values in the inward direction.

iv. The base Nusselt number increased as S/H decreased and this increase was sharp at higher values of Grashof number.

v. The average Nusselt number increased with S/H for low Grashof number while it decreased for high Grashof number.
Sane et al. [40] investigated experimentally and numerically the problem of natural convection heat transfer from horizontal rectangular fin arrays with a rectangular notch at the center. Results have been obtained in terms of $h_a$, $h_b$ and the corresponding Nusselt number $Nu_a$ and $Nu_b$. It was observed that $h_a$ increases with increase in spacing in all the cases. The increasing trend was steep up to a spacing of about 9 mm. After that there was a gradual rise as expected. The notched configurations yield values, which were 15 to 30% higher in all cases, thus indicating the superior performance of notched fin arrays.

Suryawanshi and Sane [42] investigated experimentally and numerically, natural convection heat transfer from horizontal rectangular inverted notched fin arrays. In lengthwise short array (L/H~5), where single chimney flow pattern is present, a stagnant zone is created at the central bottom portion of fin array channel and hence it does not contribute much in heat dissipation. Hence it was removed in the form of inverted notch at the central bottom portion of fin to modify its geometry for enhancement of heat transfer. An experimental setup was developed for studying the investigation on normal and inverted notched fin arrays (INFAs). Fin spacing, heater input, and percentage of area removed in the form of inverted notch were the parameters of the study. For few spacing, it was verified by computational fluid dynamics analysis. It was found that the average heat transfer coefficient for INFAs was nearly 30–40% higher as compared with normal array.

2.3 CLOSURE

In the light of the review of literature on fin arrays, it is seen that the problem of heat transfer by natural convection from plate fins on horizontal and vertical surfaces has been studied theoretically and experimentally by a number of investigators. It has been reported that provision of a cross fin at the centre of rectangular fin array enhances the heat transfer performance. Single chimney flow pattern in plate fin array is superior from the point of view of heat removal and exists in lengthwise short array (L/H~5). A stagnant zone is created at the central bottom portion of fin array channel and hence it does not contribute much in heat dissipation. Attempts were made to make this portion effective by adding cross fin at centre and using notched fins. Baskaya et al. [24] reported
parametric study of horizontal rectangular fin arrays, but no clear conclusions were drawn because of too many influencing parameters involved.

Review of the existing literature shows that the experimental and numerical work that has been done on pin fin arrays on horizontal and vertical base with pins of different shapes under natural convection by a number of investigators. In pin fin arrays, the contribution of outer pin rows is significant and the inner rows are not as effective as outer rows. In a densely populated array, the overall heat transfer performance is poor as the top of array behaves as horizontal plate.

Investigation for exploring the possibility of enhanced performance with pin fins in horizontal rectangular plate fin arrays was suggested by Xialong Yu et al. [36] and Yue-Tzu Yang et al. [37] under forced convection condition. However, investigation of the problem of natural convection heat transfer in plate fin pin fin arrays has not been done so far. These may improve PFHS with large S/H ratios by reducing thermal resistance. Parametric studies of such arrays are also not reported so far.

Therefore, it is decided to investigate plate fin heat sink with pin fins, both experimentally as well as numerically which is the main objective of this work.

2.4 THE PROBLEM UNDER CONSIDERATION:

As has been pointed out in earlier section, no work has been reported so far on the topic of natural convection cooling with plate fin pin fin combination. Passive cooling design is more reliable even better than the inclusion of forced flow, and can reduce the damage probability caused by the cooling failures.

From the early research work and literature survey it is clear that, there is establishment of single chimney pattern for lengthwise short fins. There is sidewise entry of air in case of natural convection cooling of horizontal fin array. The air coming inwards gets heated as it moves towards the centre of the fin, as well as it rises due to decrease in density.

It is therefore logical to conclude that planting some columnar pin fins into flow passages of the PFHS to disturb air flows passing through the heat sink will improve
performance of heat sink in natural convection as found in forced convection, reported in [36,37]. This research work aims

i. To develop a numerical model for simulation studies of PFPFHS and to design and manufacture an experimental setup for validating the numerical model.

ii. To carry out evaluation of experiments and simulations and comparison of both.

The other objectives will be to find heat transfer & fluid flow characteristics from such array with the following parameters of study.

i. Heater input
ii. Fin spacing
iii. Fin height
iv. Pin fin diameter
v. No. of pin fins
vi. Location of pin fins in the fin channel
vii. Pin fin material (Aluminum and non conducting for numerical study only)

Following methodology is decided to investigate the possibility of performance improvement of horizontal rectangular fin arrays with pin fins.

i. Modification of PFHS to construct PFPFHS for evaluating performance
ii. Comparison of PFPFHS with PFHS in terms of average Nu and base Nu and the confirmation of superiority of PFPFHS arrays
iii. Study of flow patterns for PFPFHS arrays
iii. Investigation of PFPFHS arrays with different aspect ratios (L/H), (S/H), and (P/D) using CFD analysis