

Transient Thermal Simulation of Perforated Drop-Shaped Pin Fin Array in Staggared Arrangement

Manikandan.C¹, Pachaiyappan.S²

P.G. Scholar, Department of Thermal Engineering, Adhiparasakthi Engineering College, Melmaruvathur, Tamilnadu, India¹

Assistant Professor, Department of Mechanical Engineering, Adhiparasakthi Engineering College, Melmaruvathur, Tamilnadu, India²

ABSTRACT: In this paper simulation of temperature and pressure drop in a perforated drop-shaped pin fin heat sink is considered and heat transfer is increased by changing the circular pin fin arrangement into a perforated Drop-shaped pin fin in the staggered arrangement also constant heat flux is given for a better solution. The process has been tested by using ANSYS-15.0 (CFD), the perforated drop-shape with same cross sectional area is delaying the air passes through them, thereby increasing the heat transfer. The transient condition is used here to obtain a better result. Finally, perforated Drop shaped pin fins results are compared with Circular and Rectangular Shapes to justify the Drop shaped pin fin will give the better heat transfer.

KEYWORDS: component; Drop -shape, perforated, Temperature, Pressure, Constant heat flux, staggered arrangement, Transient Analysis, Heat sink.

I. INTRODUCTION

Extended surface heat exchangers are used in heat exchanging devices to increasing the heat transfer between the surface and the surroundings fluid, different types of heat exchangers fins are employed with different shapes such as cylindrical, rectangular, annular, tapered, or pin fins, these fins are attached from the rectangular or cylindrical base. One of the most commonly used extended surface heat exchangers is the pin fin, a fin pin is a cylindrical or other shaped elements is protruded perpendicular to the wall, and the heat transfer fluid is flowing in cross flow manner, different types of parameters that characterize the pin fins they are shape, diameter, height, positions, in which the fins are placed in flow direction (staggered or inline).

Fins are playing main role to enhance the heat transfer performance, the fins are modified by shape according to our convenience to get maximum heat transfer, the fins are used inside and outside the heat exchanger to improve their efficiency, pin fin used in various applications for example the cooling of circuit boards and computer chips can also use this type of cooling strategy for large heat flux removal rates which is shown in below fig-1.



Fig-1. A pin straight and flared heat sink types

In this study pin fin heat exchangers are made up of a group of solid perforated pin fins attached to the end plate of an internally forced convective air flow passage or duct. Here three different shapes of (Circular, Rectangular, Drop

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(A High Impact Factor, Monthly Peer Reviewed Journal)

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shaped) pin fin in staggered configurations with the perforation are considered and all its performances are studied by using simulation software (ANSYS-15.0 CFD).

II. RELATED WORK

Fengming Wang et al. [1] reported numerically and experimentally the heat transfer characteristics inside a rectangular channel attached with differently shaped pin fins of circular, elliptical and drop shaped with the same cross sectional area arranged in a staggered arrangement, he find out that Reynolds number is varies from 4800 to 8200. Drop shaped pin fins are delays the flow passing through it when compared to the circular pin fins, so drop shaped pin fins are most suitable configuration to the circular pin fins.

D. E. Metzger et al. [2] studied the two types of pin fin array geometries used to improve the air foil internal cooling performance, one type of array uses the circular pin fin with different cross section in flow direction, second type of array uses the oblong cross section, he concludes the staggered arrangement in oblong cross section will increases the heat transfer with the pressure drop as same as the circular pin fin.

M. K. Chyu et al. [3] studied the heat transfer improvement by using cubic pin fin array, the fin element is either cube or diamond shape. The fin arrays are arranged in both inline and staggered arrangement; the results indicate that the cubic element is always gives a highest heat transfer followed by diamond and circular pin fins. The pressure drop in the diamond shaped pin fins are greater when compared to the cubic pin fins, also staggered arrangement will give the highest heat transfer enhancement when compared to the inline arrangement.

Qingling Li et al. [4] experimentally studies the heat transfer in rectangular ducts with staggered arrays of short elliptic pin fin in a cross flow of air, the results indicate that the elliptic pin fin has higher heat transfer than that of circular pin fins and Reynolds number is ranging from 100 to 1000.

Z. Chen et al. [5] conducted an experiment on drop shaped pin fins with internal flow and he conclude that drop shaped pin fin has the higher heat transfer than the circular pin fins for the same pressure loss characteristics This means that drop shaped pin fins is delays the fluid flowing through them when compared to the circular pin fins.

Amol B. Dhumme and Hemant S. Farkade [6] reported an experimental analysis of on heat transfer improvement and the pressure drop characteristics in a cylindrical cross section with perforated pin fins in a rectangular channel. The experimental results show that the cylindrical perforated pin fins increases heat transfer than the solid cylindrical fins, both low clearance ratio and low inter-fin spacing ratio comparatively lowers the Reynolds number are suggesting for high thermal performance.

Bayram Sahin and Alparslan Demir [7] studied the heat transfer improvement and the corresponding pressure drop in the flat surface attached with square perforated pin fins in a rectangular channel. results show that the square pin fins may increases the heat transfer. The clearance ratio and inter-pin spacing ratio is influences the heat transfer.

Giovanni Tanda [8] studied the heat transfer and pressure drop in the rectangular channel attached with array of diamond shaped elements, both in inline and staggered arrangement were considered. The heat transfer rate is increased with the presence of diamond shaped elements when compared to the without pin fins in the rectangular channel.

R.F. Babu's Haq et al. [9] reported that the better ratio of the pin fin diameter to the inter-pin fin pitch in the transverse direction was 2.04 for all pin-fin systems. Whereas, the better ratio in the longitudinal direction was 1.63, 1.71 and 1.95 for polytetrafluoroethane pin-fins, mild-steel pin-fins and duralumin pin-fins respectively.

O.N. Sara et al. [10] reported an alternative method to improve the heat transfer rate it consists of the attachment with (i) providing perforations, (ii) creating a certain degree of porosity or (iii) crating slots which allow the flow to pass through the blocks. As in the case of perforated pin fins, the flow rate is increased to improve the heat transfer.

Cheng-Huang et al. [11] estimate the optimum perforation diameters of perforated pin fin array based on the appropriate temperature difference between averaged temperature and ambient temperature and system pressure drop. The analysis consists of three cases. In design 1, five design variables are used to find out the optimal perforation diameters and the aim is to minimize the ambient temperature and system pressure drop of the pin fin array. In the design 2, four design variables are varied to find out the optimal perforation diameters. In design 3, all the perforation diameters are considered to be the constant and the perforation diameter is find out by using only one parameter. In all the three design considered here is to find out the best design for perforations.

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M.R Shaeri and M. Yaghoubi [12] studied numerically fluid flow and heat transfer in a solid and perforated pin fin array that are attached with the flat plate. Their results show that the rate of heat transfer in a perforated fin is higher than the solid fins due to its larger surface area to the volume ratio.

Ismail et al. [13] estimate the different types of shapes for perforation, it includes the small channels of triangular, circular, rectangular and hexagonal cross section. The results indicate that circular perforated fins have the best thermal and fluid dynamic performances when compared to the other types in their work.

Jihad Boulares [14] experimentally investigate the drop-shaped pin fins which are attached to the rectangular duct and it is heated from both lower and upper plate, it shows the drop shaped pin fins yields a notable improvement in the heat transfer when compared to the circular.

III. MODELLING

DROP SHAPE DESIGN:

Most of the current research is concentrated on circular pin fins because that they are easy to manufacture. However, it is clear that the perforated drop-shaped pin fins have lower resistance to the flow and lower friction factor than the circular ones, as well as a higher surface wetted area that can increase the heat transfer.

In this study, a drop shaped pin fin is selected to improve the heat transfer and pressure loss. The configuration of the pin is shown in fig-2. Its cross section consists of a circular leading edge that extends along $90+2\times\theta$ deg and a triangle edges are tangent to the circular arc.

The distance between the center of the circle triangle apex is L . Having the triangular portion of the pin will help to increase the wetted surface area of the heat exchanger leading to a major increase in the heat transfer and the efficiency. In addition, it delays the separation in comparison with the circular cross section which helps decrease the friction factor and the flow resistance leading to the major decrease's in the pressure loss.

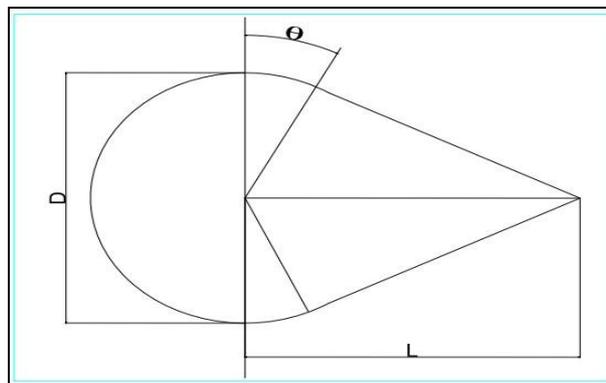


Fig-2. Drop-shaped design

By changing the pin shape from round to drop, there is an increase in the wetted surface area to exchange the heat with the flow, which increases the total heat transfer rate. By having the tail in the drop case the separation is delayed which leads to decreases in the friction drag and power.

By overlapping also creates a nozzle effect due to the angular shape of the pintail causing the flow to accelerate and collide with the subsequent row of pins. The interaction of the pins and the accelerating flow together with the coalescence lead to more turbulence, which help to increase the heat transfer.

A through experimental characterisation of different possible shapes is a very expensive and time consuming task, due to the enormous cost of experimental parts and tools. In addition, there is little geometric flexibility built into test models, and a new model has to be constructed for each different configurations.

Numerical study can be the remedy for that offering a quick and cost effective means of study with the advantage of having great flexibility in the geometry and boundary conditions.

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Many configurations can be studied at different Reynolds numbers and turbulence levels, and many different pin shape arrangements can be investigating, after selecting an optimum heat exchanger design based on the numerical study, an experiment can be conducted on a far narrow range of options to validate the predicted performance of the heat exchanger design.

PRO-E (PTC CREO-3.0 PARAMETRIC) is used to create the different types of pin fin arrays. The following table shows that parameters used to create the model.

PARAMETERS	DIMENSIONS
Pitch between two adjacent fins (P_1)	10 mm
pitch between two staggered fins (P_2)	10 mm
Diagonal pitch (P_d)	12 mm
Base plate thickness (t)	5 mm
Base plate area (A)	50×50 mm ²
Diameter of the perforated hole (d)	3 mm
FOR CIRCULAR PIN FINS	
Diameter of the circular pin fin (D)	6 mm
Height of the circular pin fin (H)	20 mm
FOR RECTANGULAR PIN FINS	
Length of the rectangular pin fin (L)	8 mm
Breadth of the rectangular pin fin (B)	4 mm
FOR DROP-SHAPED PIN FINS	
Diameter of the drop-shaped pin fin (D)	6 mm
Length of the drop-shaped pin fin (L1)	6 mm

Table-1. Dimensional parameters of pin fins

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The models are created in the PRO-E (PTC CREO-3.0 PARAMETRIC) are saved in to the format which is required for ANSYS-15(FLUENT) and it is imported.

The following are the models crated by using PRO-E (PTC CREO-3 PARAMETRIC):

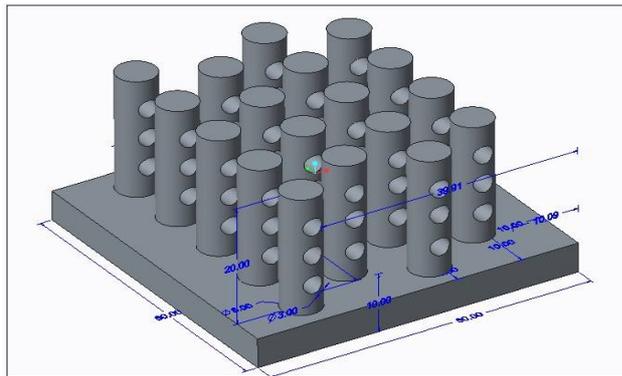


Fig-3. Perforated Circular shaped pin fin array

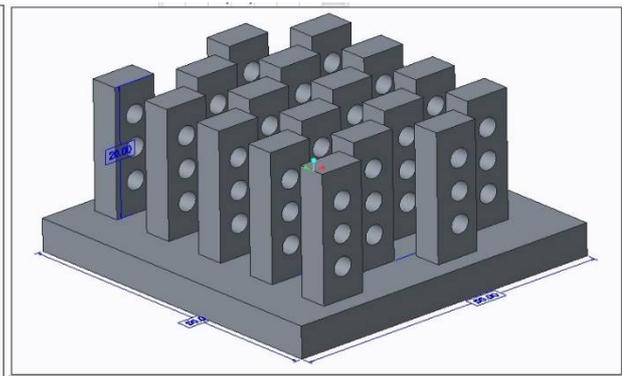


Fig-4. Perforated Rectangular shaped pin fin array

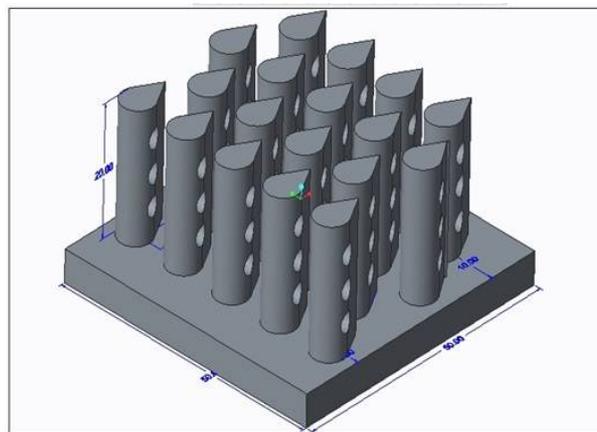


Fig-5. Perforated Drop shaped pin fin array

IV. FLUENT ANALYSIS STEPS

The models created in the PRO-E (PTC CREO-3 PARAMETRIC) are imported in to the ANSYS (FLUENT) for analysing the geometries to get the effective shape of the pin fin.

A. MESHING:

A high quality mesh is very important for successful numerical simulations. The smaller the size of the element near the wall of the pin fins, the more detailed and accurate flow structure will be captured. However, a small change in the size of the element will lead a substantial increase in the number of elements for a 3D simulation. That will result in a significant increases of computational time. To balance the accuracy of the simulations and solution time, an optimum size of mesh need to be chosen.

Here in fluent rectangular duct is created in the design modeller and meshing are done by FINE method to get the precise meshing for better results. The naming is given as per the following table:

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MESHING	NAMING OF THE ANALYSIS MODEL
FINE	FIN BASE
FINE	FIN WALL
FINE	INLET
FINE	OUTLET

Table-2. Analysis models naming

The following are the MESH MODELS crated by the ANSYS-15 (FLUENT MESH):

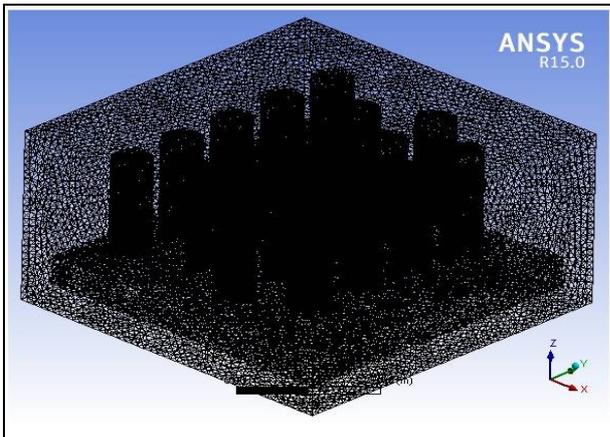


Fig-6. Mesh model for Perforated Circular pin fin array

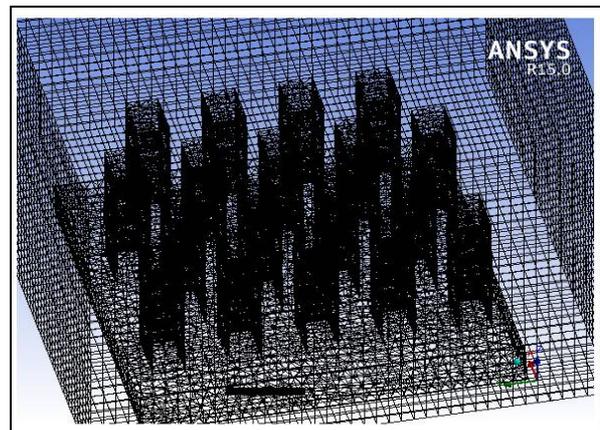


Fig-7. Mesh model for Perforated Rectangular pin fin array

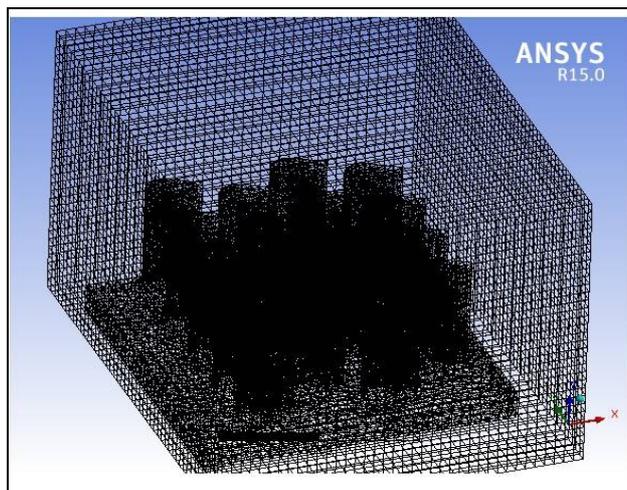


Fig-7. Mesh model for Perforated Drop-shaped pin fin array

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B. SOLVER SETUP:

After meshing the analysis model, it can be solved by setting the boundary conditions it is given below:

BOUNDARY	FLOW SIMULATION	HEAT TRANSFER EQUATION
INLET	Fully developed velocity profile	Velocity of 5m/sec, Uniform temperature at 300 K
OUTLET	Zero pressure outlet	$\frac{\partial T}{\partial X} = 0$
FIN BASE	Constant heat flux	Constant heat flux of 5000 w/m ²
FIN WALL	Standard no slip walls on no penetration	Adiabatic wall

Table-3. Boundary conditions

After setting the boundary conditions the model can be solved by standard initialisation up to the solution is converged then the results are analysed below.

V. RESULTS

A series of numerical analysis have been conducted by fluent and the results are presented in order to show the effects of heat flux in rectangular channel heat sinks.

A. TEMPERATURE CONTOUR:

For the prediction of fluid flow and thermal characteristics, contour of temperature in the fluid at the Fin pin array is shown in below fig.

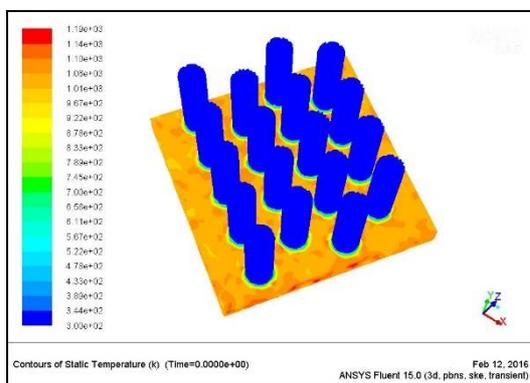


Fig-8. Temperature contour for Perforated Circular pin fin array

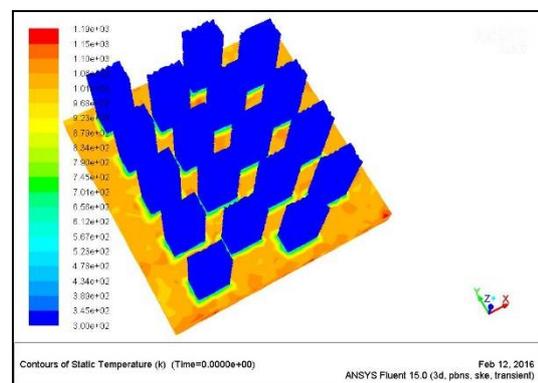


Fig-9. Temperature contour for Perforated Rectangular pin fin array

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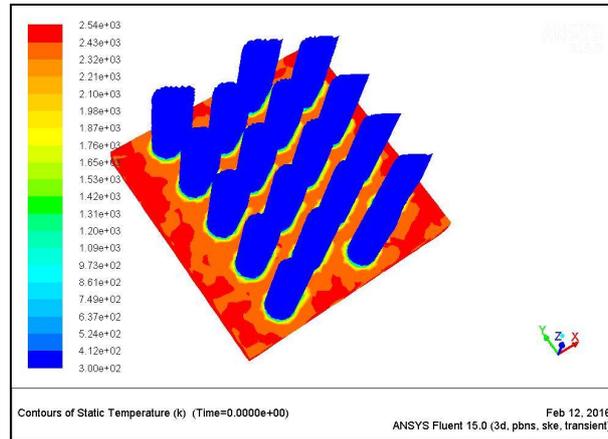


Fig-10. Temperature contour for Perforated Drop-shaped pin fin array

The above fig are the static temperature contours of the Circular, Rectangular and Drop-shaped pin fin, the fig itself tells that the heat transfer in Drop-shaped pin fin array is somewhat higher than the Circular and Rectangular shaped pin fin arrays. The heat transfer is higher in the fin base and it is decreased to the fin tip.

The temperature induced is increases in the pin fin array will causes the serious damages into the pin fin array it must be dissipated as early as possible to avoid the melting and other problems the above temperature contour will clearly tell that the temperature induced in the Drop-shaped pin fin array is somewhat lesser than the other two shaped pin fin array we are considered.

The Drop-shaped pin fin with the perforation will increases the contact between the air flow medium and pin fin arrays this will increase the heat transfer when compared to the Circular and rectangular with perforations.

The following are the pressure results obtained in Histogram plots in ANSYS for circular, drop shape and rectangular shapes in XY plot X axis is for pressure quantity and for Y axis is for position.

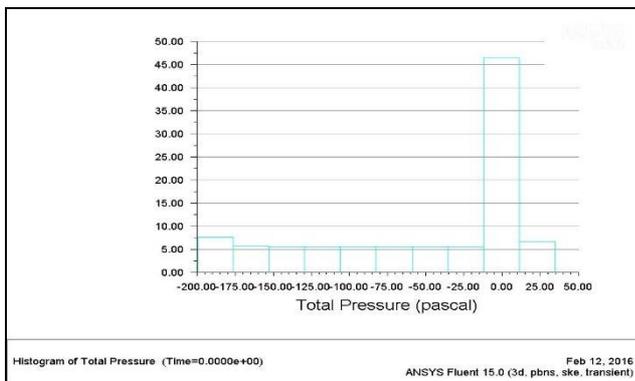


Fig-14. XY Plot for total pressure drop in a Circular pin fin array

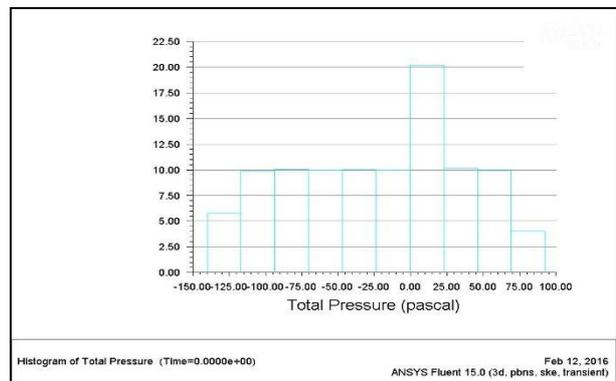


Fig-15. XY Plot for total pressure drop in a Perforated rectangular pin array

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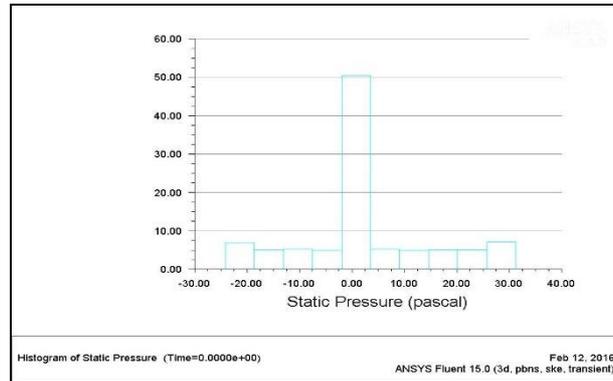


Fig-16. XY Plot for total pressure drop in a Perforated Drop-shaped pin fin array

The above fig shows the how the pressure varies with the positions of the pin fin array in rectangular duct where the forced air supply is given by the blower for heat transfer. The pin fin array is heated by using the heater with heat flux of 5000W/m^2 and the heat transfer is occurred with forced convection.

The perforated round pins seem to have a wider separation region in the back, marked by a very small velocity indicating the discontinuity of the flow streamlines and the circulation of the flow downstream of the pins. This problem was solved by changing the pin geometry and using the Drop-shaped pin fins.

The main advantage in delaying the separation in reattaching the flow after the separation is the decreases in the pressure drop mainly due to the frictional drag in the case of the drop pins. This proves that decreases in pressure drop increases the heat transfer.

The heat transfer behaviour alone does not provide a complete evaluation of heat exchanger performance. The increases in pressure drop, which is a measure of the energy required by the system, must be weighed against the improvements of heat transfer for each pin fin configurations. This optimisation process is critical for improving energy efficiency and comparing the contrast between the heat exchanger gain and losses.

The above fig tells that the Drop-shaped pin fin array is high heat transfer when compared to the Circular and Rectangular pin fins for the more or less same pressure drop.

B. COMPARISION BETWEEN FINS:

The following table is the overall a comparison between PERFORATED CIRCULAR, DROP SHAPES and RECTANGULAR SHAPES.

TYPE OF PIN FIN ARRAY	MAXIMUM STATIC TEMPERATURE (K)	MAXIMUM TOTAL TEMPERATURE (K)	STATIC PRESSURE DIFFERENCE (Pa)	TOTAL PRESSURE DIFFERENCE (Pa)
CIRCULAR	450	367	95	51
RECTANGULAR	500	366	115	80
DROP-SHAPED	440	349	101	49

Table-4. Comparison between fins

The results show that the PERFORATED DROP Fins are more reliable than the PERFORATED CIRCULAR and PERFORATED RECTANGULAR SHAPED Fins and temperature induced is varies between circular and drop fins and with appropriate equal pressure drop is this shows that temperature induced is reduced means more heat transfer rate is created in the DROP Shaped Pin Fin arrays.

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VI. CONCLUSION

The perforated drop shaped pin fins is increases the heat transfer when compared to circular pin fins for the same pressure drop characteristics. The main reasons that explains are follows:

- The perforated drop-shape have a higher wetted surface area leading to a higher heat flux.
- The perforated drop-shape forces the separation to delay.
- The drop-shape have a considerable decrease in the friction factor in comparison with the circular and rectangular shaped pin fins.

VII. FUTURE SCOPE

The study may enhance to conduct and experimental analysis of the Circular, dropped and rectangular shaped pin fin in the rectangular duct with different perforation shapes and its values are compared with numerical model to get more efficient shape of pin fin.

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BIOGRAPHY



MANIKANDAN.C currently doing M.E. in Thermal Engineering at Adhiparasakthi Engineering college, Melmaruvathur, Tamilnadu. He did is Bachelor degree in A.C.T college of engineering, Anna university, chennai.



Mr.Pachaiyappan.S currently working as a assistant proffessor at Adhiparasakthi Engineering college, Melmaruvathur. He has teaching experience of last eleven years. He completed M.E. in Thermal Engineering at Adhiparasakthi Engineering college, Melmaruvathur.