OPEN ACCESS INTERNATIONAL JOURNAL OF SCIENCE & ENGINEERING

VALIDATION AND PERFORMANCE OF PIN FINS USING CFD

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Abstract- Fins (Extended surfaces) are mainly use to increases the heat transfer rate, there are different types of fins such as cylindrical, rectangular, square, annular and tapered fins. Mostly in many cases cylindrical pin fins are used as extended surface, the proposed model of pin fins equipped with rectangular enclosure having cross section $250 \times 100\ \mathrm{mm}^2$ and length is 1020mm.For CFD simulation the following data of experimental analysis is used such as a Reynolds number ranges from 13,500 to 42000, clearance ration (C/H) = 0, inter fin spacing ratio S_y/D = 3.417,No. of fins are 11 for staggered arrangement. Then CFD results for single elliptical perforated pin fins are obtained and validated with experimental results. The proposed model is analyzed using CFD for two circular perforation and the results shows that the use of the two circular perforation leads to heat transfer enhancement than the solid and single elliptical perforated cylindrical fins. This benefits arise due to not only the increased surface area but also heat transfer enhancement near perforations through the formation of localized air jets.

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I INTRODUCTION

One of the primary goal in the design of modern thermal system is the achievement of more compact and efficient heat exchangers. Reducing energy loss due to ineffective use and also enhancement of energy transfer in the form of heat has become an important duty for the design engineer of thermal system. Extended surfaces (Fins)are use to increase heat transfer rate from the base(Heated) surface in large no of applications. Types of fins such as cylindrical, rectangular, square, annular and tapered or pin fins. One of the commonly use heat exchanger fins is the pin fin. Many industrial systems have critical components which must be cooled at sufficient rate to avoid damaging and overheating. The fins expose to the flowing fluid which cools or heats it, with high thermal conductivity of fins allowing increased heat being conducted from base through the fins. By using the suitable design of fins the requirement of excess power to cool down the surface decreases. Extended surface gives the required heat transfer rate in several application like automotive heat exchangers, engine and turbine blade in the aerospace industry ,thermal reactor, cooling of oil transport pipe line which runs several kilometer, cooling of computer processor, electronic cooling.

Nomenclature

D	Pin diameter, mm
d	Perforation diameter of the pin fin, mm
H	Pin fin height, mm
h	Heat transfer coefficient, W/m^2.K
k	Conductivity of air
n	Number of perforations
N	Number of pins
L	Base plate length, mm
P	Fan power, W
T	Temperature, ˚C
Q	Power applied on the base, W
U	Average Air velocity, m/s
I	Current
R	Resistance of heater element
V	Voltage, V
$\mathrm{T_{in}}$	Temperature in
$\mathrm{T_{out}}$	Temperature out
T_s	Surface temperature
$\mathrm{h_{av}}$	Average heat transfer coefficient

T_m	Mean temperature
N_p	Number of pin fins
N_u	Nusselt number
N_{us}	Nusselt number of smooth surface
A_s	Heat transfer surface area ,m^2
D_h	Hydraulic diameter, m
Δp	Pressure drop, Pa
P_r	Prandtl number
S_y	Pitch in stream wise direction, mm
Re	Reynolds number
ΔT	Temperature difference, ˚C
r	Radius of perforation.
υ	Kinematic viscosity of air (m^2/s)
ρ	Density of air (kg/m^3)
P	Perimeter of the fin (mm)
a	Semi major axis of ellipse
b	Semi minor axis of ellipse

II LITERATURE REVIEW

Amer Al-Damook, et al. , complete the research is , An experimental and computational investigation of thermal air flows through perforated pin heat sinks. The present study has shown that the use of multiple pin perforations can have performance benefits by enabling the heat transfer to be increased.

Mr. AshishB.Samarth, Dr. Nishikant W. Kale, Thermal Analysis Of Cylindrical Perforated Fins In Staggered Arrangement By CFD In this paper , the overall heat transfer, friction factor and the effect of the various design parameters on the heat transfer and friction factor for rectangular Tunnel equipped with Cylindrical cross-sectional perforated pin fins and Solid Fins for Staggered arrangement & Inline arrangement are investigated experimentally and computationally by using ANSYS FLUENT 14.5 Software. The maximum heat transfer rate is observed at Reynolds number (43,500), Streamwise distance Sy/D (1.944) in Staggered arrangement.

Mr. Amol B. Dhumne and HemantFarkade, Studied the Heat transfer analysis of cylindrical perforated fins in staggered arrangement. In this study, the overall heat transfer, friction factor and the effect of the various design parameters on the heat transfer and friction factor were investigated experimentally. The most important parameters affecting the heat transfer are the Reynolds number, fin spaces (pitch) and fin height.. The maximum heat transfer rate was observed at 42,000 Reynolds number, 3.417 Sy/D and 50 mm fin height. The most effective parameter on the friction factor was found to be fin height.

Bayram Sahin, et al. , Thermal performance analysis and optimum design parameters of heat exchanger having perforated pin fins. This paper reports the heat transfer enhancement and corresponding pressure drop over a flat surface equipped with circular cross section perforated pin fins in a rectangular channel. Nusselt number and friction factor were considered as performance parameters. The optimum results were found to be Reynolds number of 42,000, fin height of 50 mm and streamwise distance between fins of 51 mm.

III EXPERIMENTAL DATA

Tunnel had an internal cross-section of 250 mm width and 100 mm height . The total length of the channel is 1020 mm. The Reynolds number range used in this experiment was 13,500–42,000, which is based on the hydraulic diameter of the channel over the test section (Dh=142.85mm).

Heater Unit (test section) has a cross-section of 250 mm x 250 mm , thickness is 6mm. The heater output has a power of 200 W at 220V and a current of 10 A. The fins have a circular cross section of 15 mm x 15 mm and are attached on the upper surface of the base plate as shown in Fig. 1. C/H (Clearance ratio) is 0, and perforated at the 17 mm from bottom tip of those by an 8 mm diameter drill bit for this a= 4.8 , b= 4.constant spacing between the spanwise directions is 18.125 mm, with S_y/D = 3.417 spacing between the pin fins in the streamwise direction. Inlet air at temperature of 300 ˚K. The convective heat transfer rate ‘’Q” convection from electrically heated test surface is calculated by using

$$Q_{conv} = Q_{elect} - Q_{cond} - Q_{rad}$$

Here,

Q_{conv} = Heat transfer by convection

Q_{elect} = Electrical power

Q_{cond} = Heat transfer by Conduction

Q_{rad} = Heat transfer by radiation

$Q_{elect.}$= I²R

$$Q_{conv.} = h_{av} A_s \left[T_s - \left(\frac{T_{out} + T_{in}}{2}\right)\right]$$

Hence, the average convective heat transfer coefficient have could be deduced via.

$$T_m = \frac{T_{in} + T_{out}}{2}$$

$$h_{av} = \frac{Q_{conv.}}{A_s\left[T_s - \left(\frac{T_{out} + T_{in}}{2}\right)\right]}$$

Total area = Projected area + Total surface area contribution from the blocks

A_s =

$WL + [\pi DH - 2\pi ab]N_p + [(2\pi r^2 + 2\pi rD) - 2\pi ab]N_p$(for Perforated Fin)

This equation for elliptical perforation.

$$A_s = WL + \pi N(HD + ndD - \frac{nd}{2})$$

This equation for circular perforation.

A_s = WL + [πDH] N_p(for solid fins)

The dimensionless groups are calculated as follows:

$$N_u = \frac{h_{av}D_h}{k}$$

$$R_e = \frac{D_h U}{\upsilon}$$

$$N_{us} = 0.077 R_e^{0.716} Pr^{\frac{1}{3}}$$

CFD Methodology

As per the objectives of proposed work, analysis of pin fins is to be carried out using CFD software . One of the version of CFD i.e. Fluent 15.0 is used for analysis. Since experimental results are available for S_y/D ratio 3.417 in literature, initially model development and analyzed. Once the developed CFD model is validate with the available experimental results, the pin fins model of different parameter are developed on similar lines. Initially geometry of pin fins in ANSYS Workbench is created, then CFD steps are followed analysis and fluid flow over the pin fins is studied. The heat transfer rate is obtained at different velocities.

Geometry creation and Mesh generation

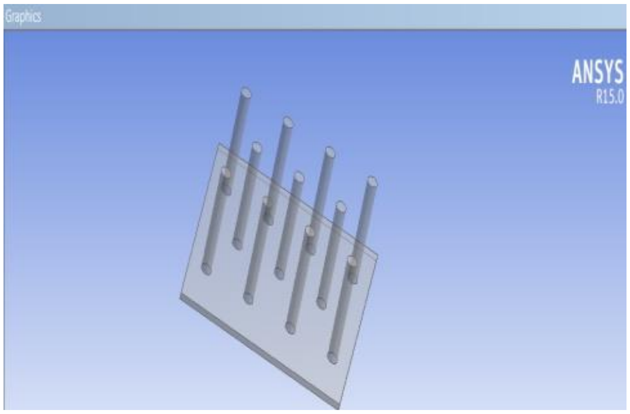

Figure 1. Geometry creation

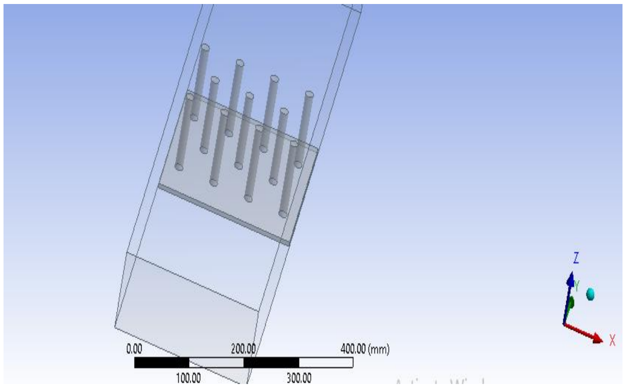

Figure 2. Domain creation

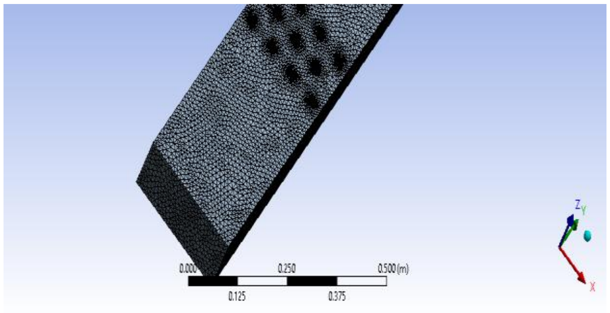

Figure 3. Mesh generation

The figure 1 is created with the help of given data in ANSYS Workbench using Square plate, circle, extrude and generation command then it is necessary to generate domain i.e. the box around the fins for fluid flow simulation (as figure 2 showing). Then the unstructured mesh generated to the model as shown in figure 3 having 725340 elements and 140343 nodes. After mesh generation, ANSYS Fluent 15.0 version of CFD is used for showing the CFD simulation using k-ε model after giving boundary conditions in pre solver and finally obtained the CFD results and visualized it in post.

Certain assumptions are made for the ease of solving the models are given below.

1)The fins are with adiabatic tip

2)The fluid, air is assumed to be incompressible.

3)Air properties are taken at film temperature.

4)The flow is steady, laminar.

5)The radiation heat transfer is negligible.

Boundary conditions applied

- Heat Load applied to base.
- Air enters into enclosure through inlet, at atmospheric temperature of 300 K.
- After passing through the heat sink air enters into atmosphere, so at outlet atmospheric pressure is assumed.
- No-slip conditions Ux = Uy = Uz = 0 are imposed along the heat sink walls. All remaining walls are considered to be adiabatic.

Post Analysis

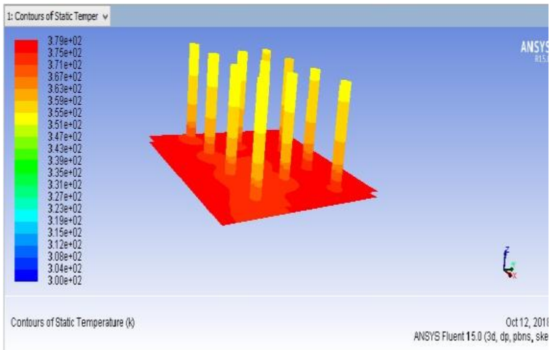

Figure 4. Temperature contours having single elliptical perforation at velocity 1.47

At 1.47 m/s velocity temperature of base is maximum as we goes upward from base to fins tip temperature decreases as shown in figure also the temperature of fins in first row shows less temperature as compare to last row show in figure 4.

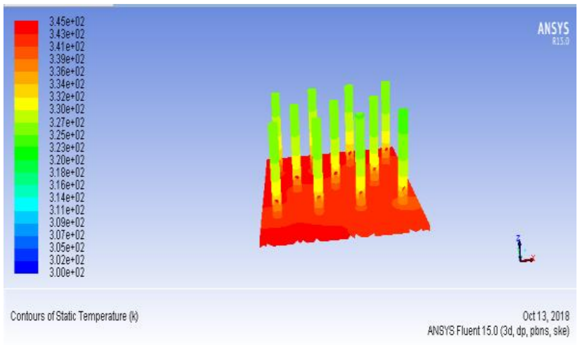

Figure 5. Temperature contours of fin having single elliptical perforation at velocity 4.47.

At velocity 4.47we found that as velocity increases the base and fins temperature decreases as compare to velocity 1.47 as shown in figure 5

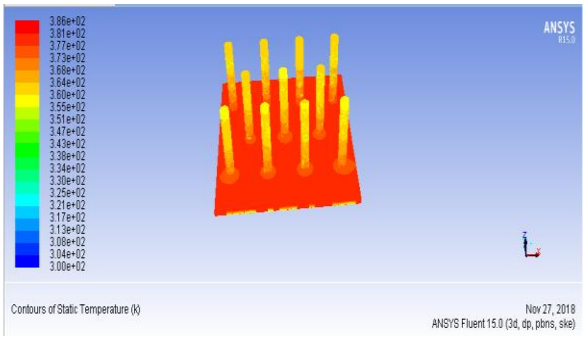

Figure 6. Temperature contours of Solid fins at velocity 1.47.

At 1.47 m/s velocity temperature of base is maximum as we goes upward from base to fins tip temperature decreases as shown in figure also the temperature of fins in first row shows less temperature as compare to last row show in figure 6.

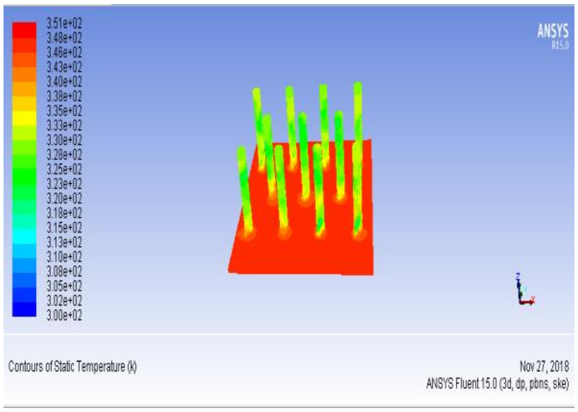

Figure 7. Temperature contours of Solid fins at velocity 4.47.

At velocity 4.47we found that as velocity increases the base and fins temperature decreases as compare to velocity 1.47 as shown in figure 7

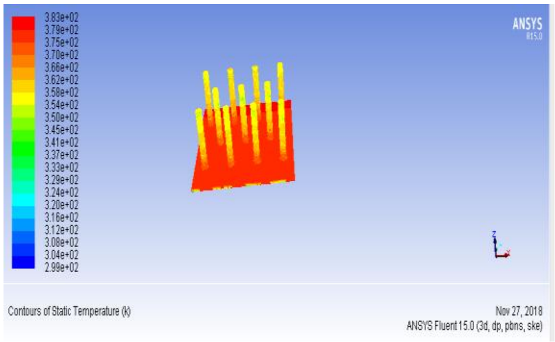

Figure 8. Temperature contours of single circular perforation at velocity 1.47.

At 1.47 m/s velocity temperature of base is maximum as we goes upward from base to fins tip temperature decreases as shown in figure also the temperature of fins in first row shows less temperature as compare to last row show in figure 8.

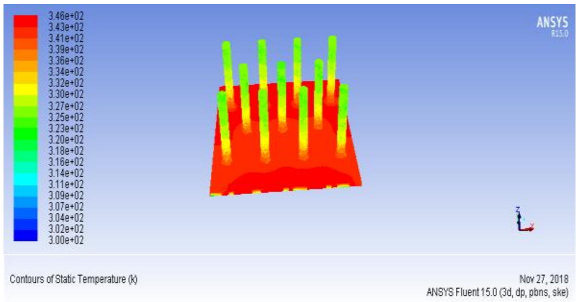

Figure 9. Temperature contours of single circular perforation at velocity 4.47.

At velocity 4.47we found that as velocity increases the base and fins temperature decreases as compare to velocity 1.47 as shown in figure 9

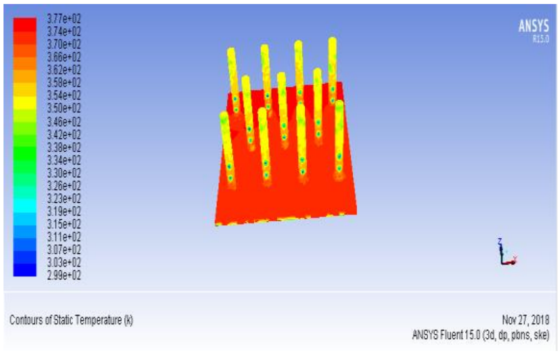

Figure 10. Temperature contours of two circular perforation at velocity 1.47.

At 1.47 m/s velocity temperature of base is maximum as we goes upward from base to fins tip temperature decreases as shown in figure also the temperature of fins in first row shows less temperature as compare to last row. Also as number of perforation increases the base temperature decreases show in figure 10.

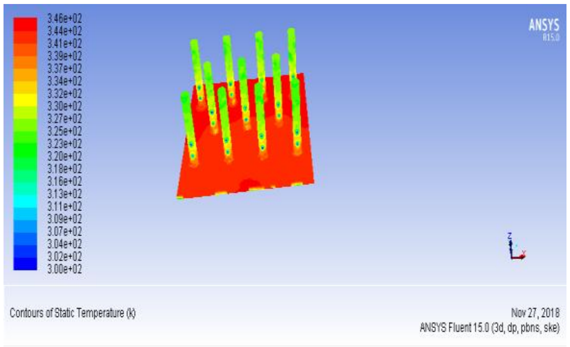

Figure 11. Temperature contours two of circular perforation at velocity 4.47.

At velocity 4.47we found that as velocity increases the base and fins temperature decreases as compare to velocity 1.47 . Also as number of perforation increases the base temperature decreases show in figure 10.

Validation

Developed CFD model of pin fins and validate with available experimental results from the literature [3]. For the current research, one of the pin fins model taken for validation i.e. pin fins having elliptical perforation. The following graph represents the graph between$N_u/N_{us}$and shows the comparison between CFD results and experimental results and the graph between N_u/N_{us} V_s R_e

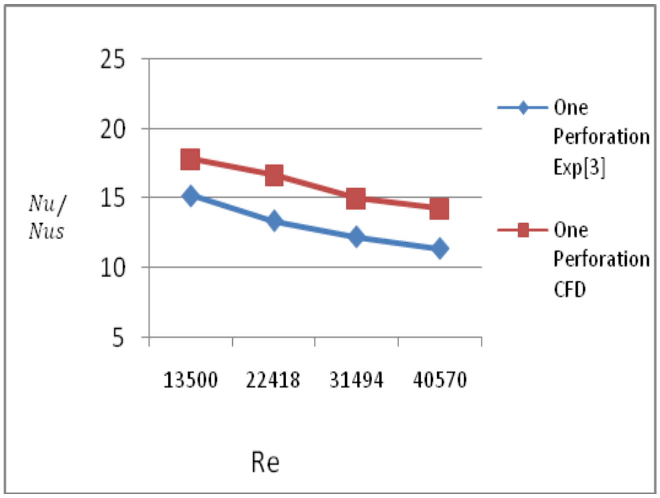

Figure. 12. Single elliptical perforation, staggered arrangement, S_y/D = 3.417 pin fins results.

The N_u/N_{us} and Re results are plotted in figure 8 shows the comparison and validation of the experimental and CFD results. The nature of the curve and values of N_u/N_{us} for the CFD and experimental results are more or less matching. This indicates that the methodology followed for the CFD model developed is satisfactory.

IV RESULTS AND DISCUSSION

We developed the model having two circular perforation of diameter 8.7632mm and CFD simulation is carried out with newly developed models for 2 circular perforation fins arranged in staggered arrangement with S_y/D = 3.417. So obtained that at Reynolds numbers 31494 and 40570 gives the heat transfer rate more than the one elliptical perforation CFD results as shown in figure 9

Table 1 CFD and experimental values of N_u/N_{us}

Re	N_u/N_{us}				
	One elliptical perforation exp	**One elliptical peforation CFD**	**Solid Pin Fin CFD**	**One circular perforation CFD**	**Two circular perforation CFD**
13500	15.20	17.83	17.20	17.95	18.51
22418	13.40	16.68	14.86	14.88	15.28
31494	12.25	15.02	13.86	14.51	14.46
40570	11.42	14.26	13.16	14.42	13.33

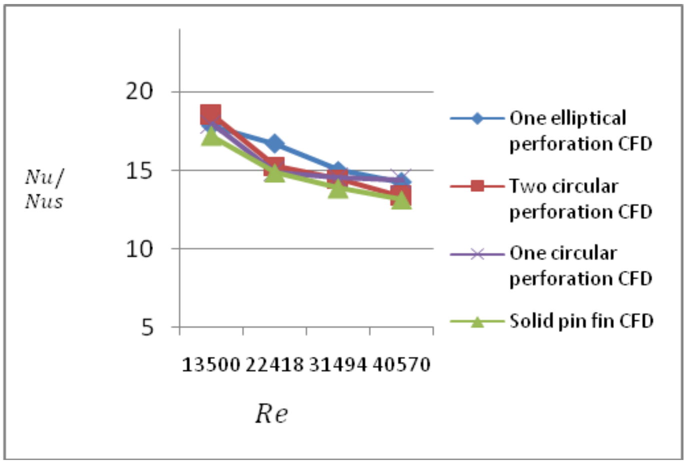

Figure. 13. Comparison of CFD results of one elliptical, circular peroration, two circular perforation and solid fins

The N_u/N_{us} and Re results are plotted in figure 9, this figure shows that the heat transfer rate at Re 13500 of Pin fin having 2 continuous circular perforation is maximum as compare to the other geometry configuration showing in figure 9 graph. The increase in heat transfer rate for two circular perforation may be due to increase contact area to the air flow, turbulence created in perforation carries maximum heat can be reason for increase in heat transfer rate.

V CONCLUSION

In proposed work heat transfer analysis of perforated pin fins is done using Computational fluid dynamics and validate with experimental results.

1] For case of having staggered arrangement, S_y/D = 3.417 ratio, single circular perforation gives the N_u/N_{us} = 17.95 which is maximum than single elliptical perforation and leads to increase in heat transfer.

2] For case of having staggered arrangement S_y/D 3.417 ratio, two circular perforation gives the N_u/N_{us} = 18.51 which is more than the solid , single elliptical and circular perforation, as N_u/N_{us} ratio increases heat transfer rate increases.

3] The optimum result obtained for the pin fins having staggered arrangement S_y/D 3.417 ratio and two circular perforation.

4] In CFD gives better results because of no losses and surface finish of perforation.

5] Because of perforation number increases weight of the sink decreases.

6] Along length of perforated fin temperature drop is higher as compare of solid fin.

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