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Analysis of heat transfer characteristics under forced convection in a rectangular body with circular fins

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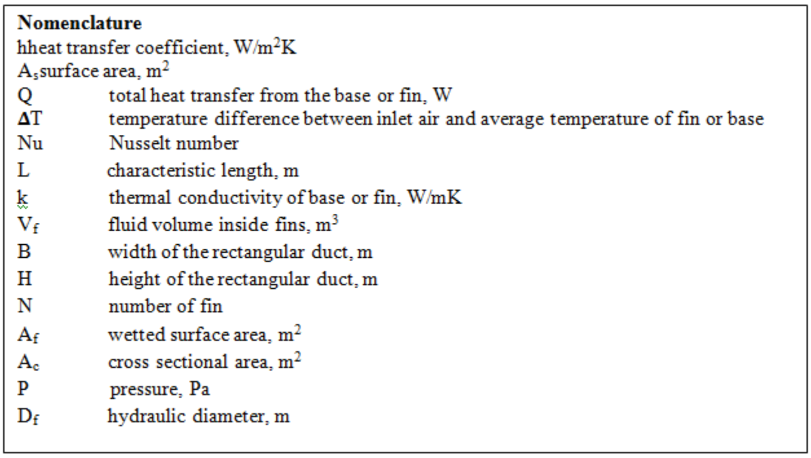
ABSTRACT: *Heat transfer in a rectangular body embedded with circular fins cooled by forced convection was numerically investigated. The arrangement considered is vertical rectangular body with staggered arranged horizontal fins. Rectangular body is heated with a constant heat flux. Simulation software was implemented to observe different heat transfer characteristics in the rectangular body andfins separately. Pressure drop, temperature distribution and velocity profile across the fins was observed varying the fluid speed around the fins. This investigation provided a higher pressure loss as the fluid speed is higher. Heat transfer enhancement at fins was higher at lower fluid speed compared with higher fluid speed and heat transfer enhancement at base was higher at higher speed compared with lower fluid speed.*

I. INTRODUCTION

In advancement of Mechanical and electrical engineering, the necessity of quick heat removal is increased. Use of extended surfaces (i.e., fin) under forced air flow is a suitable solution for this problem. Different arrangements of circular fins are used in various cooling system for electronic equipment, chemical process, high performance heat exchangers and energy system equipment. Owing to this fact, fins have been the topic of many studies [1–3] and a typical analysis is found in many text books [4-5].It becomes very important to investigate the factor upon which the heat removal rate depends. In order to significant improvement in convective heat transfer from the heat sink, it is important to know the variation of velocity , pressure drop, heat transfer coefficient in flow field at different flow velocity.

G.J. Van Fossen [10] shows the heat transfer from array of staggered shaped pin fin with varying length and fin angle.D.E. Metzger, R.A. Berry, J.P. Bronson [11] shows the effect of different fin spacing on heat transfer for staggered array of pin fin.D.E. Metzger, C.S. Fan, S.W. Haley [12] shows that array orientation between staggered and inline can give better heat transfer.The physical situation considered in this study is vertical rectangular body with staggered arranged horizontal fins,which is made of Aluminum. Heat is transferred by conduction along the fins from rectangular body and rectangular body is heated with a constant heat flux.Heat is removed from the surface of the fin via convection.

Fengmingwang et al [6] shows the vorticity and nusselt number change in rectangular duct with drop-shaped pin fins. Evan small *et al*shows the variation of heat transfer coefficient and pressure drop across the heat sink (plate Fin type). Yoavpeles et al [8] shows the variation of flow resistance and pressure drop across the pin fin bundle.In our current study, Change of velocity, temperature and pressure drop of air are shown in plot at different air flow velocity. Change of Nusselt number and heat transfer coefficient are also shown in graphical form to compare the performance of pin fin and flat base. This study mainly focused on change of above mentioned parameter with the change of air flow velocity.A Finite Element Method (FEM) is developed and simulation software is employed that allows for variable materials property effects. Grid independency and convergence issues are associated with the numerical procedure.



Nomenclature

h	heat transfer coefficient, W/m^{2}K
A_s	surface area, m^2
Q	total heat transfer from the base or fin, W
ΔT	temperature difference between inlet air and average temperature of fin or base
Nu	Nusselt number
L	characteristic length, m
k	thermal conductivity of base or fin, W/mK
V_f	fluid volume inside fins, m^3
B	width of the rectangular duct, m
H	height of the rectangular duct, m
N	number of fin
A_f	wetted surface area, m^2
A_c	cross sectional area, m^2
P	pressure, Pa
D_f	hydraulic diameter, m

Geometry description

A typical schematic of a circular fin staggered arrangement is shown in the figure below.

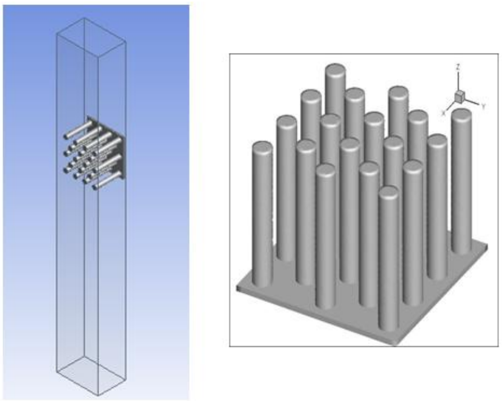
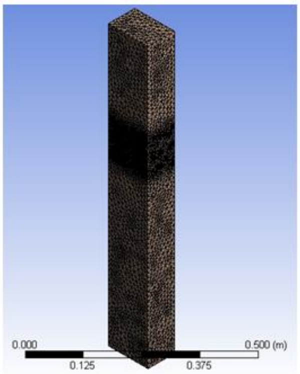


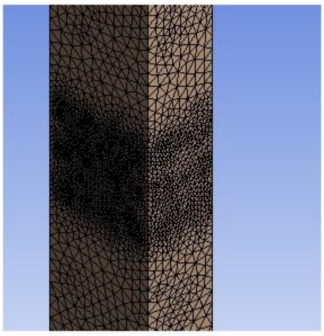
Fig.1. Staggered arrangement of circular fin.

The arrangement were designed as a rectangular duct with 18 numbers of fins having uniform cross sectional area and tested in the current study. The length and entry section of the duct were 85 cm and 50 cm respectively. The duct cross section was 106 X 50 mm. The diameter and length of the fins were 12 mm and 73 mm respectively. The corresponding base wall dimension was 106 X 106 mm. The uniform flow was ensured at the entry section of the duct length.

Meshing

Finite Element Method (FEM) was implemented to investigate the heat transfer through a rectangular body embedded with circular fins. Entire mesh was divided into fine mesh for precise outcome. Also this investigation was made up at different grid number and the changes in results were insignificant.





There are total 123693 nodes and 717529 elements. Grid independency test is also done for this experiment.

Boundary condition

A 50W heater is used to heat the base wall. Fin base is heated with constant heat flux. Heat transferred from the base to the fin by conduction and from fin to atmosphere by convection. Some amount of heat is also removed by convection from fin base where fin is not attached.Air enter into the rectangular duct with 300 K temperature and air exit from duct at atmospheric pressure.

II. NUMERICAL MESH

Computational Approach

Finite element method is used to solve the problem. All result are calculated at steady state, Iteration are continued until rate of heat produced in fin base by heater is equal to the rate of heat removed by convection from fin base and fin. Thus steady state is achieved at each velocity condition.

Calculation

In our current study fin and fin base are examined separately. Heat transfer coefficient are calculated from the following equation

$$h = \frac{Q}{\Delta T A_s}$$

Heat transfer coefficients are calculated both for fin and fin base. Q is the total heat transfer from the fin or fin base. And A_s is the surface area. **Δ**T is the temperature difference between inlet air and the average temperature of fin or fin base.

Nusselt Number is also calculated from following equation

$$Nu=\frac{hL}{k}$$

Where, L is the characteristic length. In our current study we use hydraulic diameter as characteristic length. Procedure described by wang et al. [1]is followed in determining hydraulic diameter.

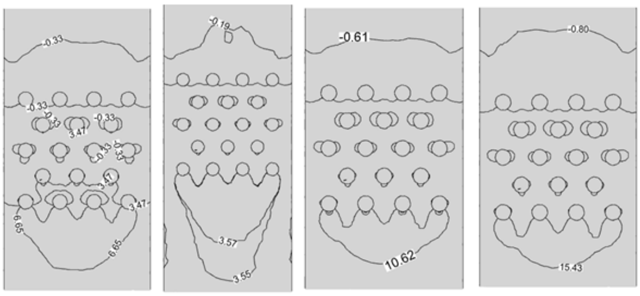
$$V_f = BHL - NA_cH$$

$$A_f = 2(B+H)L + NPH$$

$$D_f = \frac{4V_f}{A_f}$$

III. RESULT AND ANALYSIS

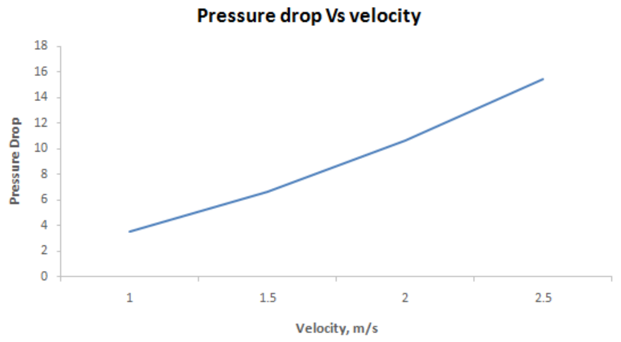
Flow Characteristics



(a) (b) (c) (d)

Fig.2. Pressure streamline at different air velocity (a) Air velocity = 1 m/s (b) Air velocity = 1.5 m/s (c) Air velocity = 2 m/s (d) Air velocity = 2.5 m/s.

Figure2 represents the pressure distribution at mid-section of the duct. Exit pressure from the duct is atmospheric pressure (0 Pa gauge). Upstream pressure varies according to the air velocity. Above figure depict how upstream pressure increase with increasing air velocity.



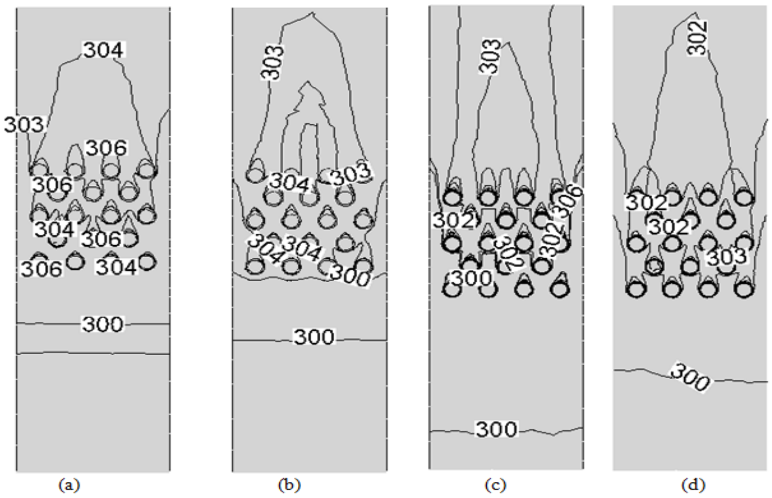


Fig. 3. Temperature distribution in midsection of the duct at (a) velocity = 1 m/s (b) velocity =1.5 m/s (c) velocity = 2 m/s (d) velocity = 2.5 m/s.

Figure 3 shows the temperature distribution in the mid-section of the duct. Air enters at a constant temperature of 300 K, whereas outlet temperature of the air varies according to the inlet air velocity. As the inlet velocity of increases, the outlet air temperature decreases. At increased air velocity, air gets less time to absorb heat from the heated fin. But mass flow rate of air increase with increased air velocity.

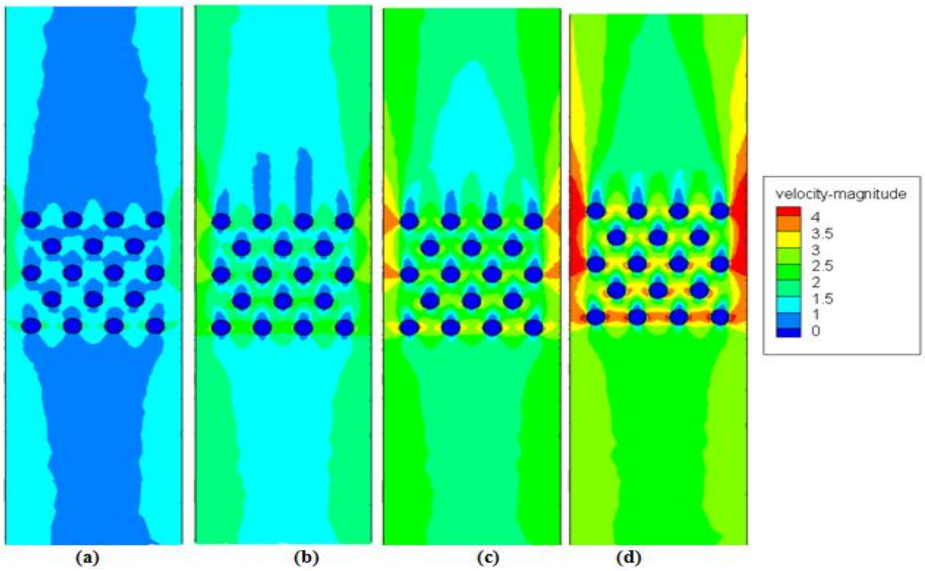


Fig. 4. Velocity profile at midsection of the duct for different free steam velocity (a) air velocity = 1 m/s (b) air velocity = 1.5 m/s (c) air velocity = 2 m/s (d) air velocity = 2.5 m/s.

Figure 4 shows the velocity profile of air inside the duct at midsection. From the velocity profile it is clear that the velocity between the two fins is always greater than the free steam velocity. Velocity after the fin is very small. This may be because of recirculation zone. This is supported by Zhau and Catton [7]. From Velocity profile we can conclude that velocity in front and rear of the fin are very small and maximum air velocity occurs at fin side wall. Heat removal rate is high at sidewall of the fin. It is possible to enhance heat transfer by increasing surface area at sidewall though introducing elliptical or aerofoil shape which is supported by several research article.

IV. HEAT TRANSFER CHARACTERISTICS

Table 1: Comparison of heat transfer (W) into the base and across the surface of the fin

Velocity, m/s	Total Heat Flux,W	Heat transfer from base, W	Heat transfer from fin, W
1	50	6.025	43.52
1.5	50	6.33	43.19
2	50	6.44	43.14
2.5	50	6.46	43.05

Table 2: Comparison of heat transfer rate (W/m^2) into the base and across the surface of the fin

Velocity, m/s	Heat transferfrom base, W/m^2	Heat transfer from fin, W/m^2
1	654.89	843.47
1.5	688.04	837.46
2	700	836.50
2.5	702.17	834.74

Table 3: Comparison of temperature difference, heat transfer coefficient and Nusselt number between the base and fin

Velocity, m/s	Reynolds number	Temperature difference		Heat transfer coefficient		Nusselt Number	
		Base(T_{base}– T_{in})	Fin(T_{base}– T_{in})	Base	Fin	Base	Fin
1	2588	20.84	17.66	31.42	47.78	49.07	74.63
1.5	3882	18.83	15.69	37.53	53.37	58.62	83.36
2	5176	17	14	41.17	59.75	64.3	93.32
2.5	6470	15.80	12.70	44.44	65.72	69.41	102.65

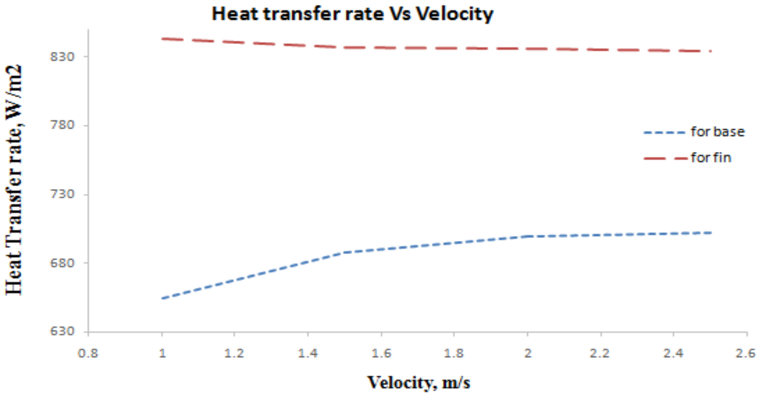


Fig. 5. Variation of heat transfer rate with velocity of air

The variation of heat transfer rate at different velocity of air is shown in Fig. 5. From this figure it is observed that heat transfer from the fin is higher than the base. As theinlet air velocity increases, the heat transfer rate from the fin decreases and heat transfer rate from the base increases.

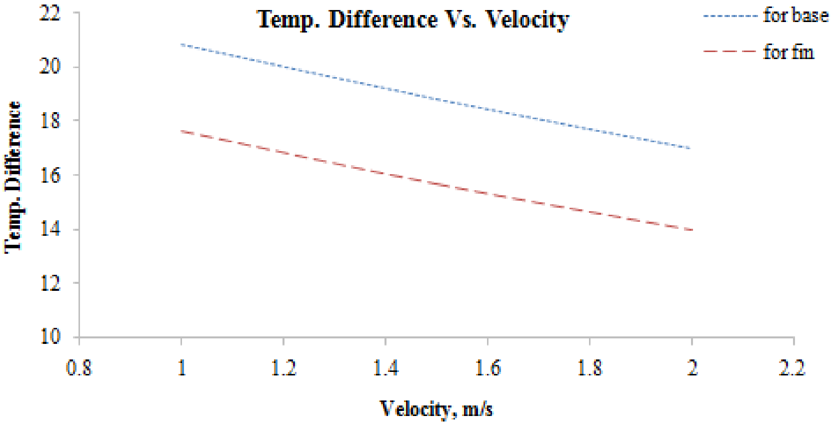


Fig. 6. Temperature difference versus velocity graph

Figure 6 shows the temperature differences between the heated body and flowing air at different velocity of air. This figure indicates that the temperature difference for both the base and fins have decreased with the velocity increment. But this temperature difference is higher for base than fin for the same condition. This happens due to the high temperature of base, which because of its vicinity to the heat source.

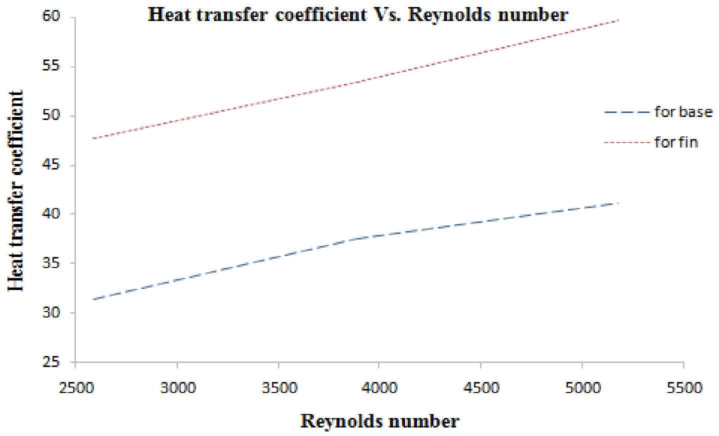


Fig. 7. Heat transfer coefficient versus Reynolds number graph

Figure 7 shows the variation of heat transfer co-efficient with Reynolds number. Heat transfer coefficient increase with increasing Reynolds number. Heat transfer coefficient is higher in base than in fin. This means more heat is transferred from per unit area of base for per degree temperature difference. As base withstand at higher temperature than base, this ensures higher heat transfer coefficient at base. Same trend we can observe in case of nusselt number in figure 8.

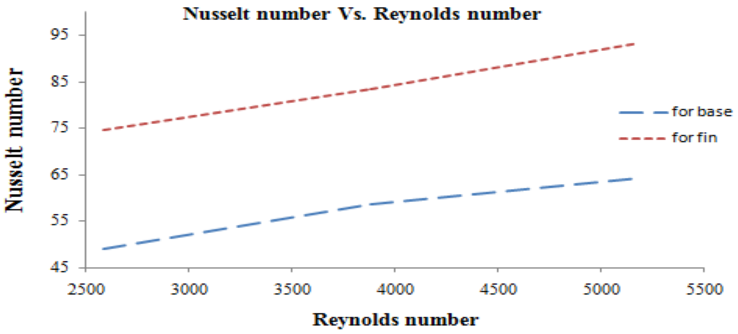


Fig. 8. Nusselt number versus Reynolds number curve

V. CONCLUSION

This paper analyzes computational results of flow characteristics along with/and heat transfer characteristics of rectangular body with staggered arranged circular fins subjected to forced convection.All the results calculated separately for the base and fins make this paper distinct. Heat transfer co-efficient and Nusselt number increase with the increase of velocity. Pressure drop across the fin was significant with the increase of inlet velocity. As the velocity increases, the heat transfer rate from the base increases and from the fin decreases.

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