Evaluation of Heat Transfer Coefficient for Plane and Perforated with Circular Perforations

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ABSTRACT: This study focuses on the analysis of extended surfaces, which are commonly employed in various engineering applications to enhance convection heat transfer. The objective is to effectively increase the heat transfer rate by introducing perforations into the lateral surface of the fins. By determining the optimal perforation design and shape for these fins, this research aids in selecting the most suitable configuration. In preparation for the examination, aluminum and copper fins are specifically selected because of their elevated thermal conductivities and extensive use in heat transfer applications. The choice is based on their respective thermal conductivities: aluminum has a thermal conductivity of 210W/mK, while copper boasts a higher thermal conductivity of 410W/mK.

KEY WORDS: Heat Transfer (HT), Heat Transfer Coefficient (HTC), Fins, Temperature and Perforations.

I. INTRODUCTION

Heat exchange between a fluid and a surface plays a crucial role in diverse circumstances [1]. In such scenarios, there are three factors that impact the heat transfer: the surface area, the temperature difference, and the coefficient of convective heat transfer [2].

The system design restricts the base surface area. The temperature variance is fixed and unchangeable based on the procedure. The only adjustable factor is the convection heat transfer coefficient, which has a maximum threshold. Attempting to increase it beyond this limit would necessitate more power for fans or pumps. Hence, the viable solution is to increase the base area by incorporating extended surfaces or fins [2]. Several types of fins are employed, such as plate fins with consistent sectional area, plate fins with varying sectional area, annular or circumferential fins with unchanging thickness, annular fins with varying thickness, pin fins with uniform sectional area, and pin fins with variable sectional area [3].

Fins offer significant benefits when dealing with situations where the convective heat transfer coefficient is at a low level. The main aim is to design fins that optimize the efficiency of heat transfer. To accomplish this objective, it is best to utilize materials with excellent thermal conductivity, such as copper or aluminum [2].

II. PRESENT WORK

This simulation research investigates the enhancement of heat transfer on a rectangular lamina by employing two different materials, copper and aluminum, without incorporating any perforations. It also explores the effect of various perforation shapes [4,5] on both copper and aluminum while maintaining a constant Reynolds number and Power Input [6,7]. After analyzing the results, the goal is to identify the best-performing perforation shape and material from the options tested..

III. EXPERIMENTAL SETUP

Figure 1 depicts the experimental setup's schematic diagram, consisting of a metal sheet material rectangular channel. Various types of perforated fins, compared to solid fins, are utilized in the experiment. Table 1 provides details of the different perforated fins, including their materials. The fins are uniformly heated at their base, and a fan is employed to generate airflow over them. The fan's position and airflow direction are illustrated in the figure. Thermocouples are utilized to measure the air temperature at the channel's inlet and outlet. The speed of the fan is adjusted to control the mass flow rate of air, which is measured using an anemometer.

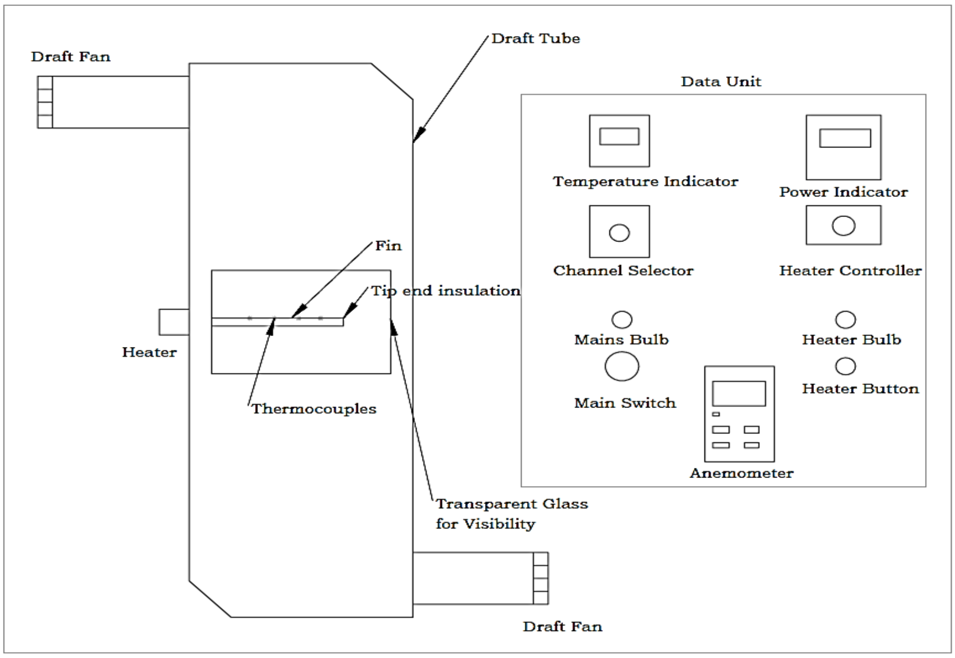


Fig1: Pin Fin Apparatus

IV. RESULTS AND DISCUSSIONS

A) Input Parameters

- The ambient temperature is at -295 Kelvin, while the root temperature is at -773 Kelvin.
- The heat transfer coefficient (H) is 20 W/m^{2}K.
- The materials utilized are Aluminum and Copper.
- The duration of the process is 500 seconds.
- The common shear area measures 400 square mm.
- The dimensions of the object are as follows: length - 150 mm, width - 50 mm, and thickness - 5 mm.

B) Output Observations

- The value of h
- The percentage by which h increases compared to an empty fin
- The temperature

C) Formula Correlations

Variation in temperature along the fin's length.

$$\frac{T_x - T_a}{T_o - T_a} = \frac{\cosh m(L-x)}{\cosh ml}$$

"The symbol 'T_x' represents the temperature at a certain distance 'x' from the root of the object, while 'T_a' denotes the ambient temperature. 'T_o' stands for the temperature at the root of the object, and 'L' refers to the total length of the fin."

Where m is given by

$$m = \sqrt{\frac{hp}{KA}}$$

The above statement explains the variables used in the context of convective heat transfer from a fin. Specifically, 'h' signifies the convective heat transfer coefficient, 'P' indicates the perimeter, 'K' represents the thermal conductivity of the material, and 'A' denotes the cross-sectional area of the fin.

$$Re = \frac{\rho V L_c}{\vartheta}$$

The statement describes the variables involved in a certain context. It states that 'ρ' represents air density, 'Lc' stands for the Characteristic length of the fin, 'V' represents the air velocity, and 'ϑ' denotes the Kinematic viscosity.

$$Nu = 0.615 \times Re^{0.466} \quad \text{For } 40<Re<4000$$

$$Nu = \frac{hL_c}{K_{air}}$$

"In this context, 'h' represents the convective heat transfer coefficient, 'L_c' denotes the Characteristic length of the fin, and 'K_{air}' stands for the Thermal conductivity of air.

Heat Transfer Rate $Q = \sqrt{hpKA}(Tanh\, mL)(\Delta T)$

Efficiency of the Fin $\eta = \frac{Tanh\, mL}{mL}$

Effectiveness of the Fin $\varepsilon = Tanh\, mL\sqrt{\frac{hp}{KA}}$

D) Rectangular Lamina with Lateral Perforations

This analysis aims to investigate the impact of various lateral perforation shapes [8-11] on the thermal efficiency of fins in contrast to solid fins. The study involves examining rectangular laminas with different types of lateral perforations, as illustrated in Figure 2.

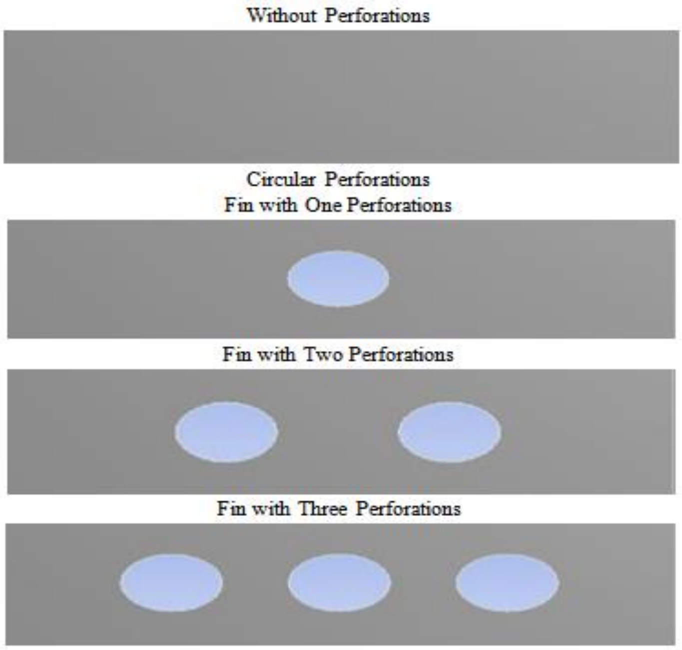


Fig 2: Rectangular Lamina with Lateral Perforations

Table 1: Rectangular Lamina with Lateral Perforations

S.No	Material	With / Without Perforations	No of Perforations		
1.	Aluminum	Without Perforations	Zero		
2.	Aluminum	With Circular Perforations	One	Two	Three
3.	Copper	Without Perforations	Zero		
4.	Copper	With Circular Perforations	One	Two	Three

E) Experimental Results

The aim of this investigation is to examine how different lateral perforation shapes impact thermal performance in comparison to solid fins [12-14]. The study begins by analyzing a non-perforated fin and then moves on to fins with circular perforations. These perforations vary in number but possess identical cross-sectional areas.

Non-Perforated: A rectangular sheet with dimensions 150 X 50 X 5 mm is being analyzed, and two materials, namely copper and aluminum, are used as references. The table provided contains information about the tip temperature and convective heat-transfer coefficient for these materials.

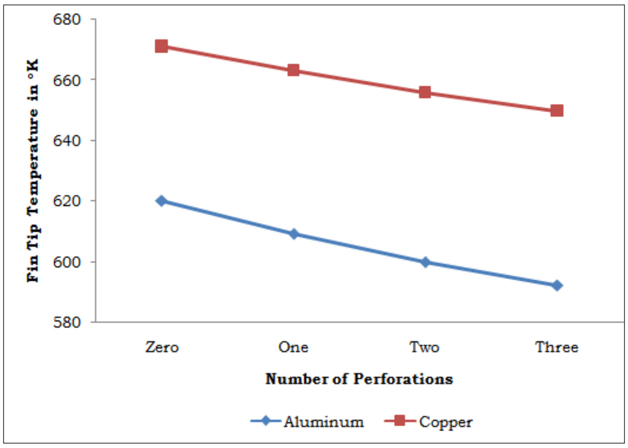
Table 2: Non-perforated Rectangular Lamina with different materials

S.No	Temperature	Material	With / Without Perforations	Tip Temp	'h' (heat transfer coefficient) W/m²K
1.	Root 773 K	Aluminum	Without (Zero) Perforations	620 K	16.21
2.	Root 773 K	Copper	Without (Zero) Perforations	671 K	17.64

Perforated with Circular Perforations: Data was gathered through experimentation on circular perforations possessing a shear area of 400mm². The quantity of holes was raised from one to three, and diverse metrics were recorded, encompassing temperature plotted against the number of perforations, the convective heat-transfer coefficient correlated to the count of circular perforations, and the percentage increase of h (heat transfer coefficient) compared to an unperforated surface as a function of the number of perforations.

Table 3: Circular-perforated Rectangular Lamina varying perforations with different materials

S.No	Temperature	Material	No Perforations	Tip Temp	'h' (heat transfer coefficient) W/m²K	Percentage increase of 'h' over blank surface
1.	Root 773 K	Aluminum	One	609.23 K	16.43	1.36
2.	Root 773 K	Aluminum	Two	599.77 K	16.62	2.59
3.	Root 773 K	Aluminum	Three	592.23 K	16.79	3.58
4.	Root 773 K	Copper	One	663.07 K	17.81	0.94
5.	Root 773 K	Copper	Two	655.72 K	17.96	1.82
6.	Root 773 K	Copper	Three	649.66 K	18.09	2.56



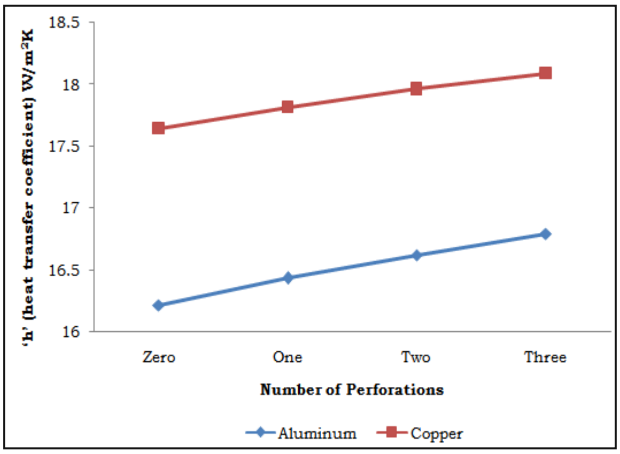


Fig 3: Temperature V/S No. of Circular Perforation Fig 4: Heat Transfer Coefficient V/S No. of Circular Perforations

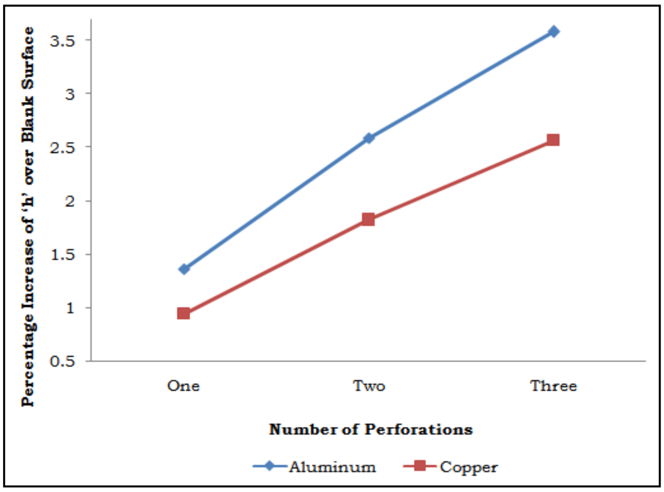


Fig 5: Percentage Increase of 'h' over Blank Surface V/S No. of Circular Perforation

- According to Figure 3, aluminum has the lowest tip temperature when it has three perforations.
- Figure 4 shows that copper has the highest initial "h" value for three perforations, but aluminum reaches a similar "h" value by the third perforation.
- Figure 5 shows that aluminum has the highest percentage increase in "h" over the blank fin for three perforated aluminum.
- Based on both temperature and "h" values, aluminum with three circular perforations is the preferable choice.

VI. CONCLUSIONS

The research indicates that for circular perforations, considering both temperature and 'h', choosing aluminum with three circular perforations is superior to copper. The results demonstrate that aluminum with three perforations has the lowest tip temperature and the greatest increase in 'h' compared to other materials. Moreover, the convective heat transfer coefficient is higher for the perforated aluminum fin in comparison to the non-perforated fin. Consequently, the most appropriate choice for fin applications would be a three circular laterally perforated aluminum.

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