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Review Article

Use of Perforated Fins as a Natural Convection Heat Transfer- A Review

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Abstract

The concept of heat transfer through perforated material is one method of improving the heat transfer characteristic in the natural convection. A solid and perforated material of brass, aluminum, copper is selected for the experimentation. As the review is concerned it is found that, the heat transfer through perforated fins is much greater than the solid one. Whenever the available surface is found inadequate to transfer the required quantity of heat with the available temperature drop, extended surfaces or fins are used. The finned surfaces are widely used in economizer for steam power plant; radiators of automobiles, air cooled engine cylinder heads, cooling coils in refrigerators and air conditioners. Enhancement of natural convection heat transfer is necessary because of the continuous increase of power consumption rate of equipment. The objective of this paper is to enhance the heat transfer by using different perforated material fins.

Keywords: *Solid fin, perforated fin, heat flux, natural convection heat transfer enhancement, heat dissipation, circular perforation*

1. Introduction

Enhancement of heat transfer is of vital importance in many industrial applications. One of the methods of enhancing heat transfer is the use of extended surfaces. The use of perforated material is limited by the lack of reliable strength and stiffness properties for the use in design. The thermal systems must be designed and sized to generate, transmit, or dissipate the appropriate amount of unwanted heat with required demand. The successful and safe operation of thermal units depends on various requirements including cooling and or heating of certain component parts. In electric and electronic systems, the generated heat may cause burning the problems that lead to system failure. To overcome this problem, efficient heat sink is essential. Natural convection from these devices is one of the considered cooling techniques and plays an important role in maintaining their reliable operation. In such circumstances, the heat sink may consume up to 40% of the total system volume.

The removal of excessive heat from system components is essential to avoid the damaging effects of burning or overheating. The enhancement of heat transfer is an important part the subject of thermal engineering. The heat transfer from surfaces may in general enhanced by increasing the heat transfer coefficient between a surface and its surroundings, by increasing the heat transfer area of the surface. Generally the area of heat transfer is increased by utilizing the extended surfaces in the form of fins attached to base of the plate. Fins, as heat transfer enhancement devices, have been quite common. As the extended surface technology continuous to grow, new design ideas have emerged, including fins made of various materials. Due to high demand for lightweight, compact, and economical fins, the optimization of the fin size of great importance. Therefore fins must be designed to achieve maximum heat removal with minimum material expenditure, taken into account, and also with the ease of manufacturing the fin shape. A large number of studies have been conducted on optimizing fin shapes. Other studies have introduced shape modifications by cutting some materials from fins to make cavities, holes, slot, grooves or the channels through the fin body to increase heat transfer areas and or the heat transfer coefficient. One popular heat transfer augmentation technique involves the use of rough or interrupted surfaces of different configurations. The surface roughness or interruption aims at promoting surface turbulence that is mainly intended to increase the heat transfer coefficient rather than the surface area.

The main objective of the present study is to investigate the effect of introducing circular perforations on heat transfer enhancement from a horizontal rectangular fin subjected to natural convection. The modified fin i.e. perforated fin is compared to a corresponding solid fin in terms of heat transfer rate. It was reported that non flat surfaces have free convection coefficients that are 50 % to 100 % more than those of flat surfaces. Several researches reported a similar trend for interrupted, perforated and serrated surfaces, attributing the improvement to the restarting of the thermal boundary layer after each interruption.

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2. Nomenclature

The following Nomenclature has been selected for the proposed experimental setup.

Ac = cross-sectional area of fin, m^2
A_f = surface area of fin, m^2
A_p = surface area of plate
H_f = fin height, mm
h = convective heat transfer coefficient, W/m^2K
k = thermal conductivity, K
L = base plate length, mm
N = Number of fins
Q = heat transfer rate, W
W = width of fin, mm
L_f = length of fin, mm
Ra = Reynolds number
N_u = Nusselt Number
T = temperature, ^oC
T_w = wall temperature, ^oC

3. Perforated Metal Design Considerations

Considering the following factors when designing with perforated metal will result in the most effective quality solution.

Material Type: - when choosing a material type, look at the both the application demands and the total product cost. More expensive high strength alloys may provide a better overall solution. If a reduction in thickness can be achieved. The stiffness and hardness of the material determining what hole sizes and pattern can be perforated. Also realize that a commonly perforated material is more readily available than a specialty one.

Hole Pattern: - Hole pattern is the arrangement of holes on a sheet either staggered or straight rows. In a staggered hole pattern, the direction of the stagger is normally parallel to the short dimension of the sheet. The standard pattern is 60^0 staggered. It is the strongest, most versatile, and economical pattern of the perforated choices. Also available are straight and 45^0 hole pattern, availability by special order.

Hole Size: - Hole size is the diameter of the perforation. MCNLCHOLES carries a wide range of round hole sizes(from 0.020 inch to one inch), and can special order any hole size required as long as it meets minimum hole size requirements.

Hole Center: - Hole center is the distance from the center of one hole to the center of the nearest hole in the next adjoining row, hole center is one of two measures of perforation spacing. The other is open area measure essentially the same property (perforation spacing).

Open Area: - Perforated sheet contain holes and material. Open area is the total area of the holes divided by the total area of the sheet and is expressed as a percent. In other words, open area describes how much of sheet is occupied by holes. If a perforated sheet has 60 percent open area, then 60 percent of the sheet is holes and 40 percent is material.

4. Literature Review

The temperature drop along the perforated fin length is consistently larger than that on an equivalent non perforated fin. For certain values of triangular dimensions, the perforated fin can enhance heat transfer. The magnitude of enhancement is proportional to the fin thickness and its thermal conductivity. The extent of the heat dissipation rate enhancement for perforated fin s is a complicated function of the fin dimensions, the perforation geometry and the fin thermo physical properties. The gain in the heat dissipation rate for the perforated fin is a strong function of both the perforation diameter and lateral spacing. This unction attains a maximum value at a given perforation diameter and lateral spacing, which are called the optimum perforation dimension and the optimum spacing. The perforation of fins enhances the heat dissipation rates and at the same time decreases the expenditure for fin materials. Abdullah H. Alessa. (2008).The perforation Average friction coefficient, pressure drop and average Nusselt number decrease with increasing perforation and solid fin has the largest value of Nu. For describing the operation of perforated fins, a parameter as perforated in effectiveness is defined that shows the enhancement of heat transfer rate from individual perforated fin in comparison with corresponding solid fin. The values of PFE are always positive that show an increase in the heat transfer rate due to use of perforated fins are alike the solid fin. For higher Reynolds numbers and in perforated fins with more number of enable. One of the most important benefits of utilization of perorated fins is reduction of fin's weight. Low weight certifies saving material of fins and related equipments such as heat sinks.M.R. Shaeri (2009). In general, perforation could enhance the heat transfer coefficient and reduce the module temperature effectively. The dimensionless temperature of heat sources decreases gradually with the holes open area ratio. The decrease in the average dimensionless temperature for two heat sources is up to 22% corresponding to β=0.2944. The average dimensionless temperature of the second heat source can be reduced to lower than that of the first heat source without perforation at S/L = 1.0 and β=0.2944. For the first heat source, the maximum augmentation, in the average Nusselt number compared with flow over single heat source is of 27% corresponding to β= 0.2944 and Re_L =10798. For the second heat source, the maximum augmentation in the average Nusselt number compared with flow over single heat source is of 8.5% corresponding to β=0.2944 and s/L=1.0 at Re_L=10798. R.K.Ali (2009). For fins with perforation, the region of recirculation over the faces of perforated fins at a fixed altitude of fin is different than solid fin but this region over of the top surface of fins is nearly the same for all types of fins studied. With increase of perforation flow becomes complicated, average friction coefficient decreases and solid fin has the highest value of C_f. For fins with perforation, drag force reduces. Also drag ratio becomes smaller by increasing Reynolds number. Average Nusselt number decreases by increasing number of perforations. By increasing number of perforations, temperature difference between the fin base and fin tip becomes larger. By making window perforations and especially with increasing number of perforations, lighter fins that are more economical will be achieved. The main advantage of these new kind of perforated fins is their considerable lower weight, lower drag force and slight higher heat transfer rate with respect to solid fin M. R. shaeri (2009).Solid pi fin heat sink performance for upward and sideward orientations shows a competitive nature, Nu for sideward arrangement was slightly higher than those for upward arrangement at high Ra. However, at low Ra, the results showed an opposite trend. For hollow/perforated pin fin heat sinks, Nu of sideward arrangement was higher than those of upward arrangement, and the % increase of its value reduced with increasing the hollow pin diameter ratio, Di/Do. E.A.M. Elshafei (2010). The more streamlined drop-shaped pin fins are better at delaying or suppressing separation when a flow passes through them, which reduce the aerodynamic penalty compared to circular pin fins. The heat transfer enhancement of drop-shaped pin fins is weaker than that of circular pin fins. The reduction in average Nusselt number between the drop-shaped and circular pins was about 24% for drop A, 26% fo drop B, and 27% for drop C. Fengming Wang (2012). Fin shapes yield Nu values within 37% of each other at high Re with triangle fins as the highest and the circle and ellipse fins lower, however the pressure drop values are greatly affected. With increasing fin height the Nu increases, however pressure drop also increases drastically. From the lowest tested fin height to channel ratio to the highest, the difference in Nu s 44% and the pressure drop differential at higher Re is almost 7.4 kpa. In keeping the fin width and the number of fins constant, the fins spacing was varied. The results showed that allowing for the maximum spacing, or the spacing equal to the fin width, the thermal performance is better by 6% with minimal pressure drop of about 5%.Fin material shows little effect on fin performance; however, fins with CNTs are not modeled as a porous media which is expected to increase the surface area that the fluid interacts with and can hasten nucleate boiling onset which could increase heat transfer performance significantly .J.F. Tullius (2012). Introducing square perforations to fin body increases surface area and heat dissipation. For certain values of perforation dimension, the perforated in can enhance heat transfer. The magnitude of enhancement proportional to the fin thickness. The gain in heat dissipation rate for the perforated fin is a strong function of both, the perforation dimension and lateral spacing. This function attains a maximum value at given perforation dimension and spacing, which is may called the optimum perforation dimension, and optimum lateral spacing. The square perforation of inclined type is preferable for low fin thickness and thermal conductivity. The square perforation of parallel type is preferable for high fin thickness and thermal conductivity. Abdullah H.Al-Essa (2004). 3-D CFD simulation was performed for rectangular solid and perforated/hollow fins under the laminar flow conditions. Calculations were carried out for a range of Reynolds numbers from 100 to 350 based on the fin thickness. Hexagonal perforated fins showed greater heat transfer enhancement performance for a fixed surface area among the types of heat sinks. Circular perforated fins have slightly higher effectively than the hexagonal perforated ones. This may due to different cross section of the fins. With the sharp reduction in the pressure drag coefficient due to perforations, the average drag coefficient also reduces and thus perforated fins require less cooling power than solid fins. Perforated fins have higher contact surface with the fluid in comparison with the solid fins and reduced average pressure drag coefficient. Thus the perforated fins have higher effectiveness than the solid fins .Md. Farhad Ismail (2013). Perforations can enhance heat transfer for isolated isothermal plate, vertical parallel plates with low H/s ratios, and vertical rectangular fins with dimensions specified. When $0.10 \leq \varepsilon \leq 0.40$, perforated holes can increase the total heat transfer rate for isolate isothermal plate and vertical parallel plates with low H/s ratios by a factor of 1.07 to 1.21, while only by a factor of 1.03 to 1.07 for vertical rectangular isothermal fins. The magnitude of enhancement is proportional to the ratio of open area. Zan WU, et.al (2012).

5. Proposed Experimental Setup and Procedure

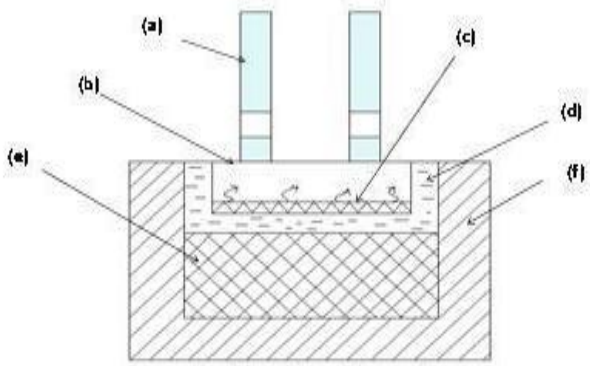

Fig.1- Sectional view of Heat Sink assembly
(a) Fin, (b) base plat, (c) Heater, (d) Gypsum, (e) Glass wool Insulation.

The above fig.1 shows that, it is a whole setup of box and consisting of fin, base plate, heater, gypsum, glass wool insulation. The main aim of experimentation under consideration is to compare the performance of solid rectangular fins over the perforated fins of the same dimensions. The apparatus consists of base plate fitted with rectangular fins on it. One is with solid fins and other with perforated fins. Heating coils inside the base surface will heat the fin. Thermocouples (copper-constantan) will measure the steady state temperatures of the various fins attached to the plate. At the base of the plate there will be a continuous supply heating to heat the whole plate, so that there will be uniformly hearting of plate and heat will pass through the fins solid as well as perforated.

By varying the constant heat input the various readings will be recorded. Similarly keeping constant mass flow rate of air and varying the heat inputs three –four sets of readings will be recorded. For the experimentation, four sets of fins are required. One set include three fins. There are three solid fins, then three perforated fins. This procedure will be repeated for all the different materials. The insulation to be provided, so that there will be less possibilities of heat transfer.

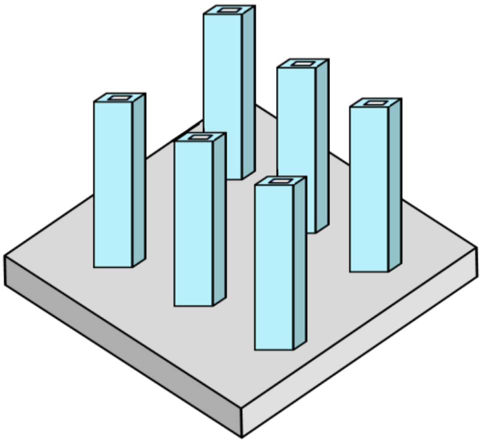

Fig.2- Base plate with fins

The above fig. 2 shows that, base plate with different types of fins and different materials. First of all reading will be taken on the performance of solid fin and then reading will be taken on perforated fins.

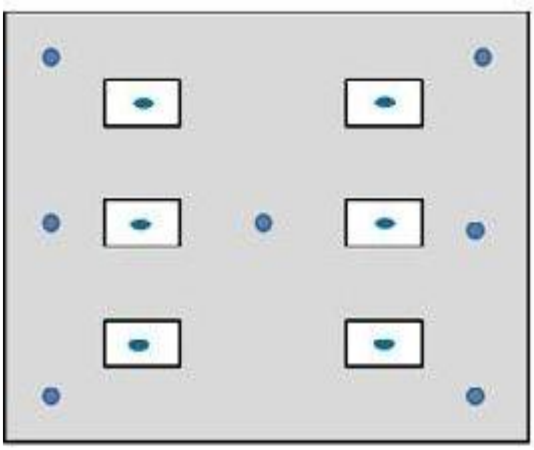

Fig.3- Thermocouple locations

The above fig. 3 shows that, on the base of the plate a various set of thermocouples will be placed also at the top and bottom of the solid fin as well as perforated fins. A pencil type of thermocouple will be taken for the experimentation.

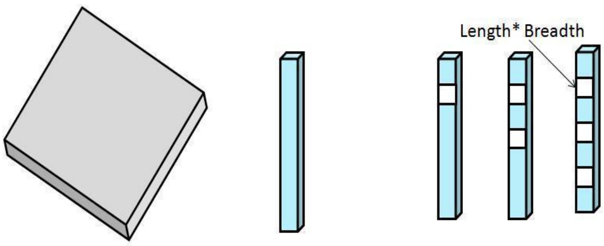

Fig.4- Different perforated fin and Base Plate

The above fig. 4 shows that, for the experimentation fins with increasing number of perforation will be taken. One set for aluminum material, in that case solid and perforated fins with single and increasing number of perforations will be taken. Second set for brass material, in that case solid and perforated fins with single and increasing number of perforations will be taken. Third set for copper material, in that case solid and perforated fins with single and increasing number of perforations will be taken.

6 Design Parameters

The following design parameters has been selected for the experimentation

Size of plate – 400*400 mm
Diameter of hole – 12 mm
Height of fin –90 mm
Width of fin – 10 mm
Length of fin – 90 mm
Material – Brass, Aluminum, and Copper

8. Conclusions

1) As far as the review is concerned, fins are the method of enhancing heat transfer.
2) The perforated fin may dissipate about 50 to 60 % more heat.
3) Heat transfer becomes more uniform by applying the perforations.
4) The fin efficiency of perforated fin is greater than the solid fin.
5) The perforated materials can have better strength.

The above results are expected after the experimentation on the setup suggested.

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