Perforated Pin Fins Array for Forced Convective Heat Transfer

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Abstract - *High-speed multifunctional electronics are being increasingly miniaturized, necessitating more severe temperature management. The use of perforated pin fins to improve the rate of heat transfer in these devices is investigated experimentally and computationally in this paper. The effects of the number of holes and perforation diameter on each pin are explored in particular. The Nusselt number for perforated pins is 47 percent greater than for solid pins, and it increases with the number of perforations, according to the findings. When compared to solid pins, the pressure drop with perforated pins is also reduced by 19%. Heat transmission via forced convection in a pin fin with circular holes as heat sinks was investigated in an experimental research. Circular perforations were among the perforation patterns. Experiments were conducted in a specially planned and built experimental laboratory. At low power, it observed a temperature decline from 35 to 31°C along the non-perforated fins, but a temperature drop from 35 to 29.8°C along the perforated fins (50 W). Temperatures dropped from 120 to 55°C for non-perforated fins and 120 to 38°C for perforated fins at the greatest power (600 W). This is because the number of perforations per pin has decreased, as has the axial heat conduction along the pin. The model that was utilized had 16 pin fins and was made out of Aluminum Alloy.*

Key Words: pin fin, round perforated, forced convection

1. INTRODUCTION

Electronic technology has been driven by rapid advancements in manufacturing technology and customer demands to increase component functionality and compactness. Electronics miniaturization causes a faster rate of power dissipation per unit volume. As a result, good thermal management is becoming increasingly important in order to maintain the operating temperature that ensures the efficiency and reliability of electronic components.

The opposing needs of maximizing thermal dissipation rate and limiting pressure drop throughout the system are optimized in the design of heat sink devices. The use of a pin fin array to a heat sink design is one of the most prevalent options. Sparrow et al. [1] investigated the heat dissipation and pressure drop effects of in-line and staggered pin fin arrays. The heat transmission and pressure coefficients for staggered arrays are greater than for in-line arrays. Khan's analytical analysis [2] came up with similar conclusions. The lengthwise and spanwise layouts of staggered and inline pins were optimized by Tahat et al. [3.] Bilen et al. [4] measured the heat transport and friction of a cylindrical finned surface experimentally. They found that in-line and staggered pin fin arrays provided much more thermal performance than a heat sink without pins. More crucially, for the same Reynolds number, the heat dissipation of staggered pins is 33% greater than that of in-line pins, albeit at the cost of increased pressure drop. Soodphakdee et al. [5] used numerical simulations to examine the impact of geometry on fins in in-line and staggered configurations, and found that circular pins outperformed square fins, while elliptical fins outperformed plate fins. The elliptical pin fin has a better heat transfer coefficient at low Reynolds numbers (Reh30), whereas the circular pin fin is more effective at higher Reynolds numbers (Reh). Pin fin arrays have a better heat transfer coefficient than plates, but they also have a higher pressure drop [6]. Short pins are circular pins with a height-to-diameter ratio of 0.5–4, whereas long pins are circular pins with a height-to-diameter ratio greater than 4 [7]. Short pins are often employed to cool gas turbine blades, whereas long pins are usually found in heat exchangers with a high heat transfer coefficient. Vanfossen [8] confirmed experimentally that long pins yielded better heat transfer rates than short pins in staggered pin fin arrays, but at the cost of increased pressure losses and hence higher pumping power requirements. The majority of research that have shown that perforations improve the rate of heat transfer in pin fin arrays have only employed a single puncture per pin. The metallic foam-like porous pins are the logical limit of this characteristic. Indeed, numerical simulations, such as those by Yang, have been conducted.

et al. [9] and Seyf and Layeghi [10] have shown that foam-like porous pin arrays can boost heat transfer rates by orders of magnitude, owing to their huge surface area to volume ratio.

Foam-like porous pins, on the other hand, may be unsuitable since they are readily contaminated, leading to closed pores and lower efficiency. Regardless, research on foam-like pins suggests that the number of holes per pin may be a key element in controlling heat transmission. The impacts of pin geometry and combinations have been investigated by several researchers. [11, 12] The magnitude of the recirculating flow behind the pins has a substantial impact on the local rate of heat transfer, according to Meinders et al. Sara et al. [13] found that increasing the size of perforation rather than the number of perforations can improve heat transfer effectiveness for a given porosity. According to Shaeri and Yaghoubi's [14] numerical simulations, the rate of heat transfer in perforated fins is substantially greater than in solid fins due to the increased surface area to volume ratio. Furthermore, the temperature differential between the top and bottom surfaces of perforated pins is smaller than that of solid pins, and it shrinks as the number of holes per pin increases. They also discovered that solid fins had a substantially greater overall drag coefficient than perforated fins, owing to the fact that solid fins make far bigger wakes than perforated pins.

The impact of the number of holes and perforation diameter on heat transfer and flow characteristics appears to be lacking in experimental and computational studies on staggered, circular, long pin fin arrays. The current research describes an experimental and computational analysis of steady-state, incompressible forced convective heat transfer in solid and staggered perforated pin fin arrays to address these challenges. The impacts of the number of perforations, N, and perforation diameter, DP, were investigated using three-dimensional (3D) Computational Fluid Dynamics (CFD) simulations.

1.1 Previous Studies

Fins, which help with heat transfer, are becoming increasingly popular. Fins composed of anisotropic composites, porous media, and perforated and interrupted plates are some of the new design ideas that have emerged as extended surface technology advances (Bayram and Alparslan, 2008). The optimization of fin size is critical due to the need for lightweight, compact, and cost-effective fins. As a result, fins must be constructed to remove the most heat with the least amount of material, easing fin production (Al-Essa and Al-Hussien, 2004). Fin shape optimization has been studied extensively. Other studies have used form alterations to enhance the heat transfer area and/or the heat transfer coefficient by removing some material from the fins to produce cavities, holes, slots, grooves, or channels through the fin body (Elshafei, 2010).

The usage of interrupted surfaces in a variety of patterns is a popular heat transfer augmentation strategy. The interruption is designed to boost the heat transfer coefficient of the surface area by encouraging surface turbulence (Kutscher, 1994). Non-flat surfaces exhibit natural convection coefficients that are 50% to 100% higher than flat surfaces, according to the study (Chung and Layer, 1993). Many other researchers have observed a similar trend for interrupted, perforated, and serrated surfaces, attributing the improvement to the restarting of the thermal boundary layer after each interruption, indicating that the increase in the convection coefficient is more than enough to compensate for any area lost (Elshafei, 2010). For a given profile area, the concave parabolic profile of a straight fin offers greatest heat dissipation (Malekzadeh et al., 2006). Rectangular fins were employed in most applications to save production costs. The ubiquitous usage of rectangular fins for heat exchangers necessitates a knowledge of convection dynamics and a forecast of rectangular fin heat transfer performance. Flow and heat transfer are typically used to study these characteristics at the same time (Suksangpanomrung et al., 2007). Mousa (2000) investigated the thermal performance of a horizontal rectangular fin with a homogeneous cross-sectional area and four vertical body perforation patterns running the length of the fin. Triangular, square, round, and rectangular holes were among the designs studied. Natural convection was utilized to analyze these patterns using the finite element method. The heat transmission of the perforated fins was found to be higher than that of the non-perforated fins.

Increases in the heat transfer coefficient and effective heat transfer surface area can improve heat transmission from extended surfaces for a given fin material, base temperature, and ambient temperature (Shaeri and Yaghoubi, 2009). Surface roughness enhanced the heat transfer coefficient of the fin surface, resulting in more turbulence. In terms of surface area, there are numerous approaches in the literature for increasing the effective heat transfer area of fins (Abdullah and Mohammed, 2009). The goal of this work is to see how increasing the number of holes affects temperature distribution, heat transfer rate, and heat transfer coefficient.

1.2 Problem Statement.

Heat production in many industrial applications can lead to overheating and, on rare occasions, system failure. Heat sinks that are efficient are critical to solving this problem. Forced convection from these devices is one of the considered cooling solutions, and it played a key role in preserving their consistent performance.

2. Experimental Setup.

Fin optimization has become a prominent concern for fin design due to advancements in heat transfer equipment such as heat sinks used in electronic devices and other systems. Fin optimization is usually done in one of two ways. The first is to reduce the volume or mass required for a given quantity of heat dissipation, while the second is to increase heat dissipation for a given volume or mass. Fins are commonly employed in heat-transfer devices to increase heat transfer between a main surface and the surrounding fluid.

Heat exchanger fins come in a variety of forms and sizes, ranging from rectangular, square, cylindrical, annular, tapered, or pin fins to a mix of geometries. The plate-fin surfaces' fins are regularly chopped into pieces or otherwise disrupted in a variety of ways. These changes are made to enhance the heat transfer coefficient and, in some cases, the heat transfer area. The alterations are made by removing portion of the fin's material to create cavities, holes, slots, grooves, or perforations in the fin's body. Fin size optimization is critical due to the increased demand for lightweight, compact, and cost-effective fins.

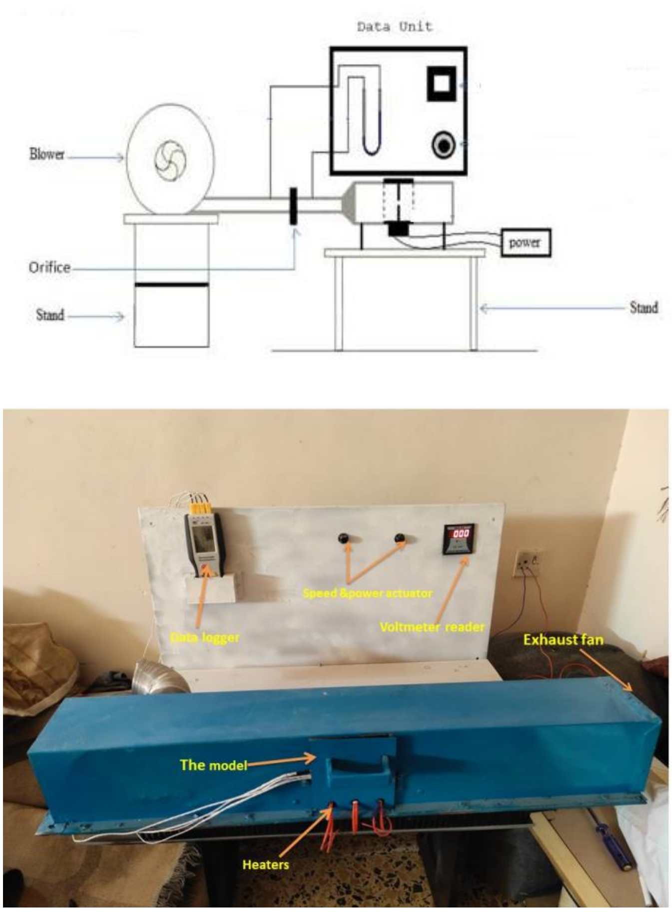


Figure.1 experimental setup used for study

Surface interruption is represented by perforated pin fins or perforated fins; this approach is used to counteract lost area by increasing the convection coefficient. Experiments were conducted Conduct in a specially planned and built experimental laboratory. The major components of the experimental setup are as follows:

1. Main duct (wind tunnel): made of aluminum sheets to evacuate particular gases while maintaining a constant flow of air to evaluate the sample.

2. Test section (heat sink): a soled brass sheet of certain dimensions is chosen for testing, and the work of the holes inside the sheet is heated by heating elements given power. Connecting pin fins constructed of aluminum with precise dimensions, including solid and perforated them in various shapes (patterns such as round, square, and rectangular perforations) on the sheet's outer surface to serve as a test sample.

3. Thermocouples, manometers, a power supply regulator, and a computer make up the data acquisition system.

4. Air blower: blows air through the tube that houses the finned surface heat sink (figure 1

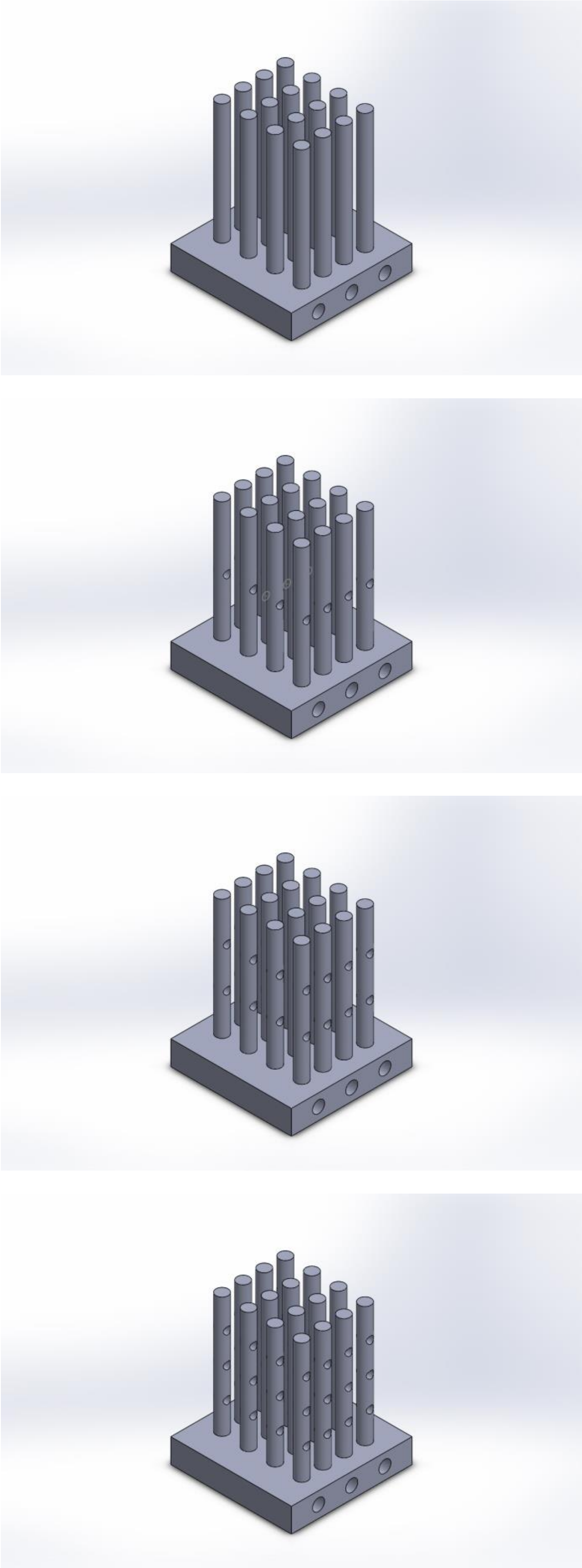
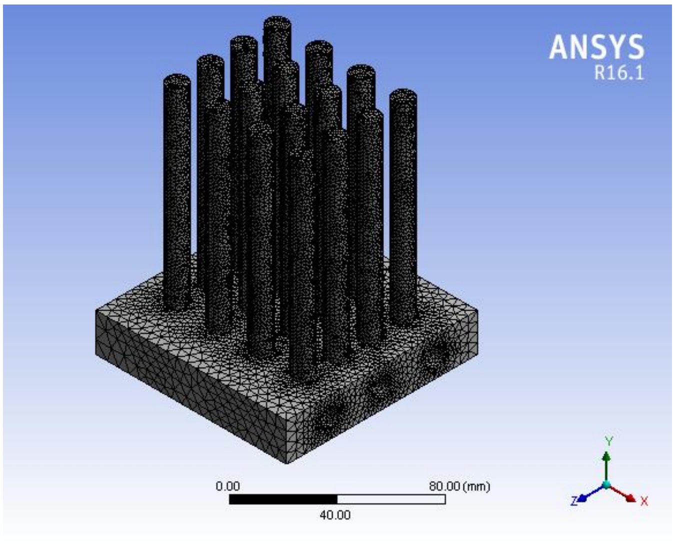
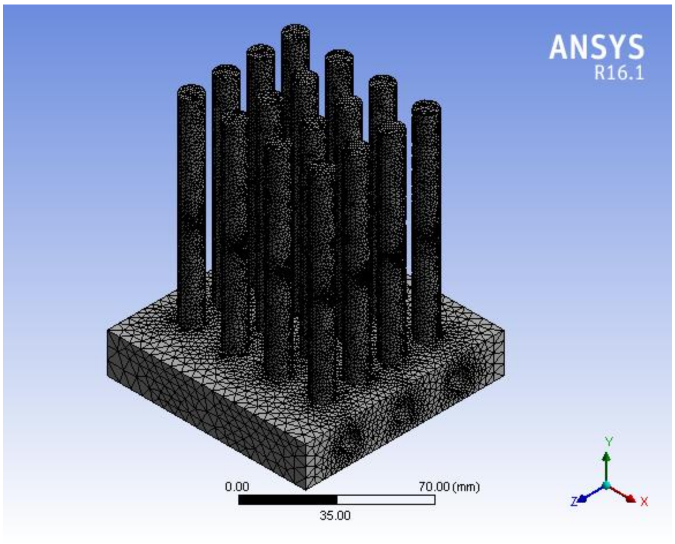
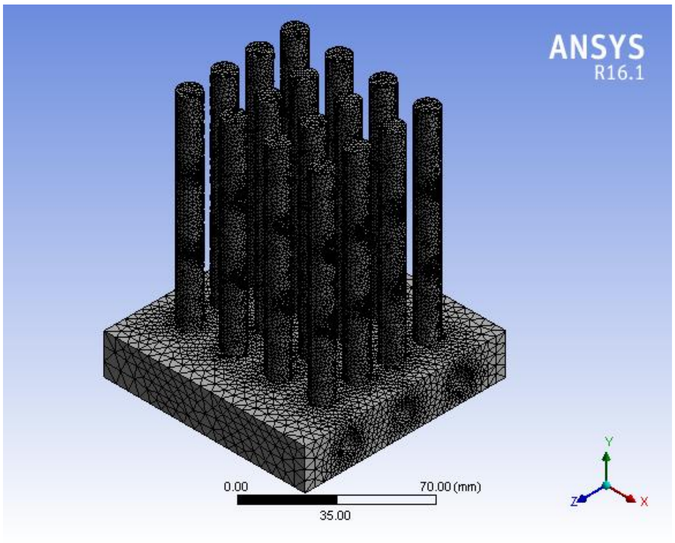


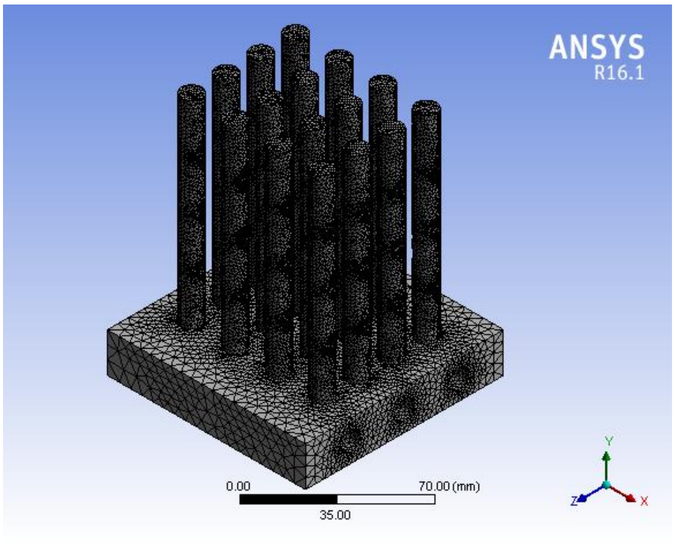
Figure.2 model of perforations

Ansys.16 was used to simulate the solid and perforated models, with a set flow of air (3m/sec) and varied heat powers provided by heater elements (3 psc 10mm diameter) mounted in the sheet plate's side base.









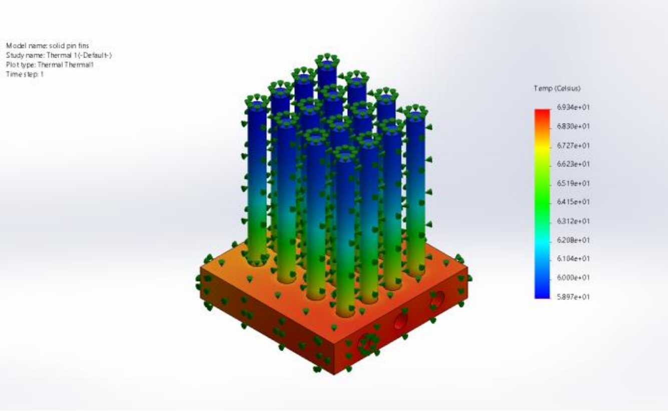


Figure.3 Temperature contour for Perforated Circular pin fin

The perforated drop-shaped pin fin will improve interaction between the airflow medium and the pin fin arrays. When compared to circular and rectangular with holes, this will increase heat transmission.

The pressure values produced in ANSYS Histogram plots for circular in XY plot are shown below. The X-axis represents pressure amount, whereas the Y-axis represents location

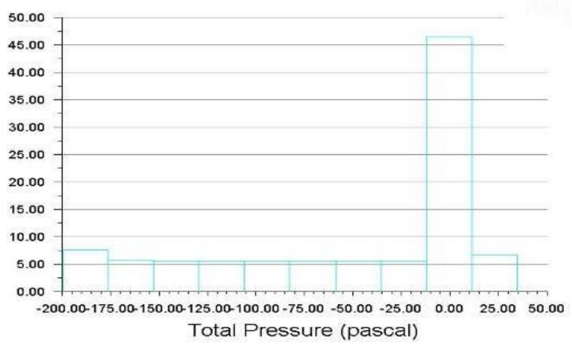


Figure.4 XY Plot for total pressure drop in a Circular pin fin array

The pressure fluctuates with the placements of the pin fin array in a rectangular duct with forced air supplied by a blower for heat transfer, as shown in the diagram above. The heater with a heat flux of 5000W/m2 heated the pin fin array, and heat transmission proceeded via forced convection. The perforated round pins appear to have a greater separation zone in the back, which is defined by a very low velocity, suggesting the discontinuity of the flow streamlines and the flow circulation downstream of the pins. Change the pin geometry and use Drop-shaped pin fins to fix this problem. The major benefit of delaying the separation and reattaching the flow thereafter is the reduction in pressure loss, which is mostly due to frictional drag in the case of drop pins. This demonstrates that lowering the pressure drop improves heat transmission.

4. Result and Discussion.

Different observations are made, such as the heat input q, i.e., Qconv. The average temperature across the fins in W. Tm1 in °C mean outside temperature Tm2 in °C, temperature difference T in °C, and h heat transfer rate in W/mm2 °C for solid pin fins, one whole pin fin, two holes pin fin, and three holes pin fins; the result shows that heat transfer increases with the number of perforations; when solid fins are compared to three holes pin fins, h increases by about 30 to 40%. In addition, as the number of perforations increases, the temperature differential reduces. This demonstrates that a little temperature differential results in a large amount of heat transfer

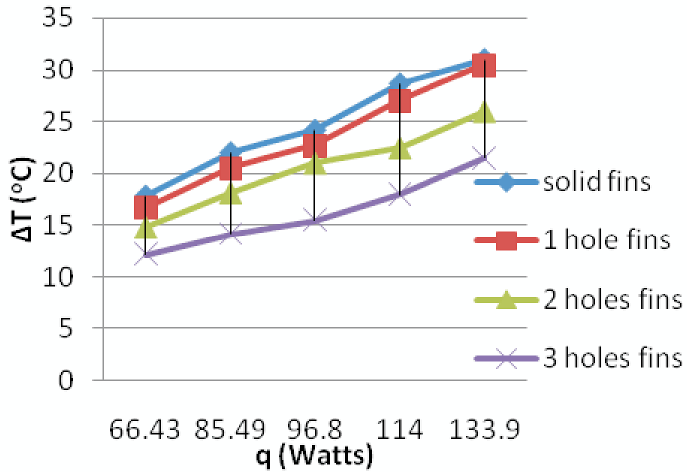


Figure 5: Graph between 'q' on X-axis and Temperature Difference 'ΔT' on Y-axis

The graph above depicts the temperature differences for the various types of fins utilized in this experiment. When compared to other fins, the temperature differential for three holes fins is lower. As a result, there will be increased convective heat transmission.

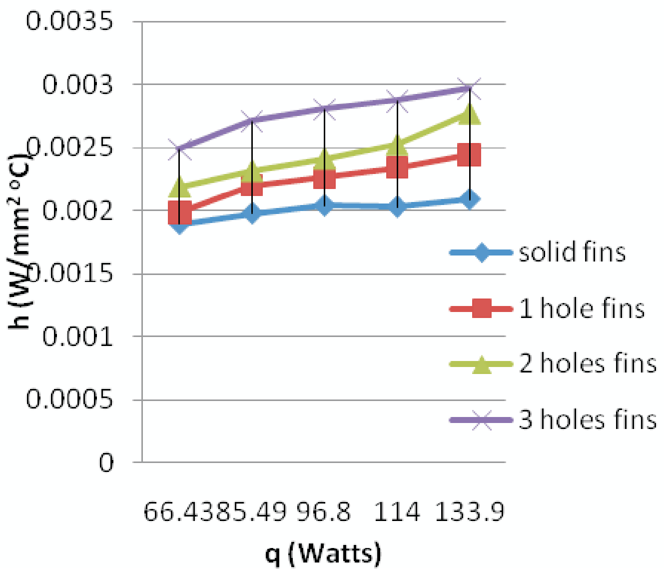


Figure 6: Graph between 'q' on X-axis and 'h' on Y-axis

The dissimilarity of the h with regard to q, i.e., Qconv, is shown in Figure.6. Fins of all kinds are welcome. The value of h fluctuates from 0.00189748 W/mm2oC to 0.00297 W/mm2oC in this case. This illustrates that when the perforation value of h grows, so does the value of h.

5. CONCLUSIONS

The results of this experiment show that:

a) Perforated pin fins transmit more convective heat than solid pin fins. As a result, we may employ perforated fins in a variety of applications that would normally need solid fins. With more holes and a larger surface area, the temperature differential becomes more significant.

b) We employed four different types of fins in our project, therefore the three-hole fin is more efficient than the others. Convective heat transfer gains 30 to 40% of its value. For various values of q, the temperature difference ranges from 17 to 31 degrees Celsius for solid fins, 16 to 30 degrees Celsius for one hole fins, 14 to 26 degrees Celsius for two hole fins, and 12 to 21 degrees Celsius for three hole fins.

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