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Experimental Investigation of Heat Transfer by Natural Convection in Perforated Rectangular Heat Sink

Darshan S[1], Dinesh S. P[2], Dushyanth Gowda K. S[3], Mr. Lohith N[4], Dr. Manu S[5]

[1,2,3] 8th Semester, Department of Mechanical Engineering, Sri Siddhartha Institute of Technology, Tumkur – 572105
[4]Assistant Professor, [5]Associate Professor, Department of Mechanical Engineering, Sri Siddhartha Institute of Technology, Tumkur - 572105

A B S T R A C T

Cooling electronic components through natural convection is significantly more challenging than using forced air cooling. This difficulty arises because the thermal resistance of a heat sink can be up to 20% higher in a natural convection environment compared to a high-air-speed environment. Various heat sink configurations are commonly used in natural convection cooling for electrical equipment, ranging from transformers and mainframe computers to transistors and power supplies.

The project attempts to experimental investigation of heat transfer by natural convection in perforated heat sink. The CREO model was developed and formulated using CNC machine. The experimented conducted in two stages, with perforation and without perforation. The perforation provided on the fin space with two diameters of 6mm and 10mm and four heat input (12.3 W, 19.37 W, 24.157 W). The results showed that highest heat transfer co-efficient for lowest perforation diameter.

Keywords: Natural Convection, Heat sink, Perforation, Heat Transfer Co-efficient, Diameter

1. INTRODUCTION

When it comes to designing heat systems, making improvements is a crucial step to achieve the best results. Excess heat is a big issue in many industries and can harm various systems like heat exchangers, car radiators, refrigerators, electronic devices, and more. One of the top to enhance heat transfer is by using extended surfaces known as fins.

Fins are considered passive methods and are preferred over active techniques due to their cost-effectiveness. The design and material of fins depend on factors like size, heat transfer rate, weight, and other economic considerations. The goal is to maximize heat transfer while minimizing the size, weight, and cost of fins.

Extended surfaces like fins are commonly used to dissipate heat from electronic components through natural or forced convection. There are various fin designs available commercially and in research literature, but the focus is always on improving heat dissipation while reducing costs.

Researchers have discovered that adding perforations to fins can significantly enhance heat transfer at a lower cost since perforated fins require less material. Additionally, perforated fins are lighter than solid fins, making them ideal for applications where weight is a concern.

Heat concentration poses a challenge for electronic components and engines where heat generation occurs. Heat sinks play a vital role in dissipating this heat efficiently. Heat sinks consist of fins attached to devices like processors in computers or internal combustion engine cylinders.

Fins have great potential for increasing heat dissipation due to their extended surface area. Factors such as fin height, width, spacing, and length influence the effectiveness and efficiency of a heat sink. It's important to consider these parameters when designing cooling systems for optimal performance.

2. LITERATURE REVIEW

Thermal performance of free convection heat transfer with vertical heat sink by providing slits along the vertical surface of the fins. For the evaluation purpose two different arrangements viz. plain finand slitted fin are selected. Fins are made from high thermal conductivity aluminium material and five dissimilar heat inputs are selected for study. The experimental and numerical findings are confirmed using the theoretical correlations available from the literature. The effect of number of slits and width of slits is investigated on convective heat transfer coefficient.

Numerical study is used to understand the flow patterns around the vertical fin surface. It has been observed that the presence of slits on the surface appreciably improves the thermal performance of vertical fin array [1].

Experimentally investigates heat dissipation by different longitudinal fins fitted to a cylindrical heat sink under natural convection conditions. Five aluminum fin configurations at base temperatures (70°C, 85°C, 100°C, and 115°C) were studied. The first fin was plain (fin1), while second fin had a triangular edge (fin2). The rest fins have the same triangular edge but with six 1cm circular perforations near the edge (fin3). While the perforations in fin4 were in the middle longitudinal fin length. The last fin (fin5) had twelve 0.5 cm circular perforations distributed into two columns. The measurements were validated with theoretical correlation with an acceptable deviation [2].

Under laminar natural convection conditions, the optimum design of a perforated branching fin for electronic cooling application is numerically investigated. Circular perforations with diameters varying between 1.1 mm and 6.6 mm are used. In this size range, the surface area of the perforated fins is less than the non-perforated fins. Two orientations of the fins are considered, namely vertical base horizontal fin (vBhF) and horizontal base vertical fin (hBvF). With a 'single' perforated branching fin, heat dissipation is always enhanced by making perforations in vBhF orientation, but it would diminish in hBvF orientation for certain pore sizes and distributions. The optimum values of perforation diameter, pitch and branching angle for heat transfer enhancement are determined to be d = 3.3 mm, PH = 1.05d, PL = 1.5d and α = 45o corresponding to a porosity of 40.5%. High plume velocities and low temperatures observed in 3.3 mm pores made it the optimum size [3].

Extended surface plays a major role in heat transfer for several heat generating devices the waste heat is dissipated to ambient by heat sink in electronic components and fins in internal combustion engines, in present study 3 configurations of tapered fin heat sink is proposed with 9 cases of heating power the computational model was created in ANSYS Fluent and analyzed with different heating power to predict heat transfer characteristics of tapered fin heat sink with taper angle of 1_, 2_and 3_with heating power of 5, 10, 20, 30, 40, 50, 60, 70 W, the 2_ tapered fin heat sink exhibits maximum heat transfer coefficient with low thermal resistance compared to other configurations of tapered fin heat sinks (TFHSs) under natural convection condition [4].

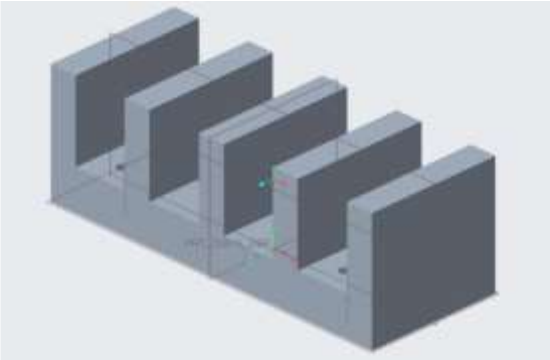
This paper deals with experimental investigations of heat transfer and friction factor characteristics of perforated pin fin heat sink tested in rectangular channel by using forced convection. Cylindrical pin fins with conical perforations on the lateral surface area were arranged in staggered arrays on base plate to form heat sink. Two combinations such as solid fins and fins with conical perforations were compared. Effect of number of conical perforations and size of conical perforation on thermal performance of heat sink was studied in detail. Theses heat sinks were subjected to variable air flow rate (10000 ⩽ Re⩾ 30000) in the turbulent regime and constant heat flux input. The results found that with increase in number of conical perforations from 2 to 5 results into higher heat dissipation rates and lowers pressure drop. With increase in size of conical perforation, heat transfer rate initially increases, attains maximum values and then decreases [5].

In this work, pin fin and plate heat sinks were investigated in terms of natural convection and radia- tion heat transfer by experimental means. One rectangular base plate and eight pin fin and plate heat sinks were manufactured particularly for this study. Eight different pin fin and plate heat sinks had four different pin fin numbers and hence pin fin spacings; and two different pin fin heights. Three different orientations of 0 °, 90 °and 180 °were tested. Ten different constant heating rates were applied to heat sinks during tests, corresponding to Rayleigh number interval between 1 ×10 6 and 7 ×10 6 . Heating powers were changed between 5 and 50 W by 5 W increments by means of DC electrical power source. All cases were compared with each other. Results were evaluated by calculating heat transfer indicators from experimental measurements, dependent Nusselt and Rayleigh numbers, and by drawing their co-responding graphics. It was detected that increasing pin fin number up to a threshold value increases thermal performance [6].

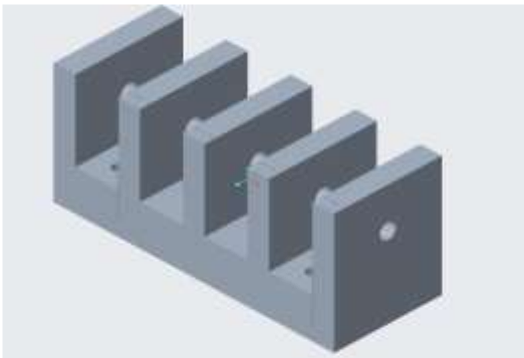
This experimental work dedicated to find the thermal performance of triangular fins in two cases, non-perforated and perforated showing the effect of input factors on the thermal performance. Experiments were carried out by testing three fins for the above two cases and the value of heat input rate with three values: 25.69, 63.58, and 136.9 W. many fixed thermocouples were used to measure the temperature in the root of the fin and points along its extension and an additional point to measure the ambient temperature. The Rayleigh number and the Nusselt number were calculated. The effect of the Rayleigh number on the Nusselt number was shown. The results showed that the total heat transfer coefficient of the air increases with the increase in heat added in both cases. In addition, it was found that the temperature decrease along the perforated fin is greater than that of the non-perforated fin, and the total Nusselt number increases with the increase in the heat rate input for both cases [7].

3. EXPERIMENTAL SETUP

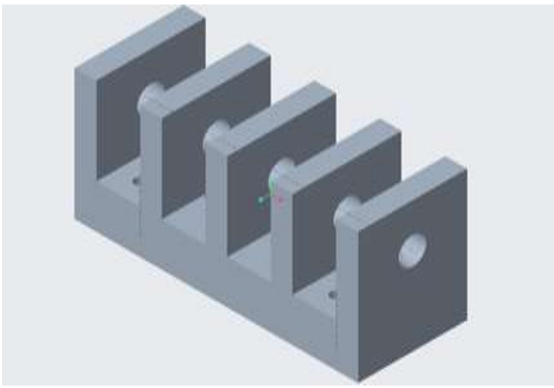
3.1 Heat Sink CREO Mode



(a)



(b)



(c)

Fig. 3.1 - (a) Model 1 Without Perforation Heat sink

(b) Model 2 With Perforation of 6mm diameter Heat Sink

(c) Model 3 With Perforation of 10mm diameter Heat Sink

Table -1: Specification of the model

Length of the model	104mm
Width of the model	40mm
Thickness of fin	8mm
Number of fins	5
Depth of the fins	32mm
Width of the fins	40mm

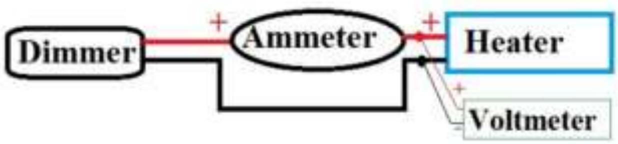


Figure 3.7: Schematic diagram of the experimental setup

3.2 Experimental Setup

1. Mount the Heat Sink:

- Secure the perforated rectangular heat sink vertically in a stable position.

- Attach the heater to the base of the heat sink.

2. Install Thermocouples:

- Attach thermocouples at different points on the heat sink to measure temperature distribution.

- Connect thermocouples to the data logger.

3. Connect Electrical Circuit:

- Connect the heater to the power supply through the dimmerstat.

- Connect the ammeter in series and the voltmeter in parallel with the heater.

4. Insulate the Setup:

- Use insulation material around the heat sink assembly to minimize heat loss to the surrounding

4. RESULT AND DISCUSSION

4.1 Temperature History

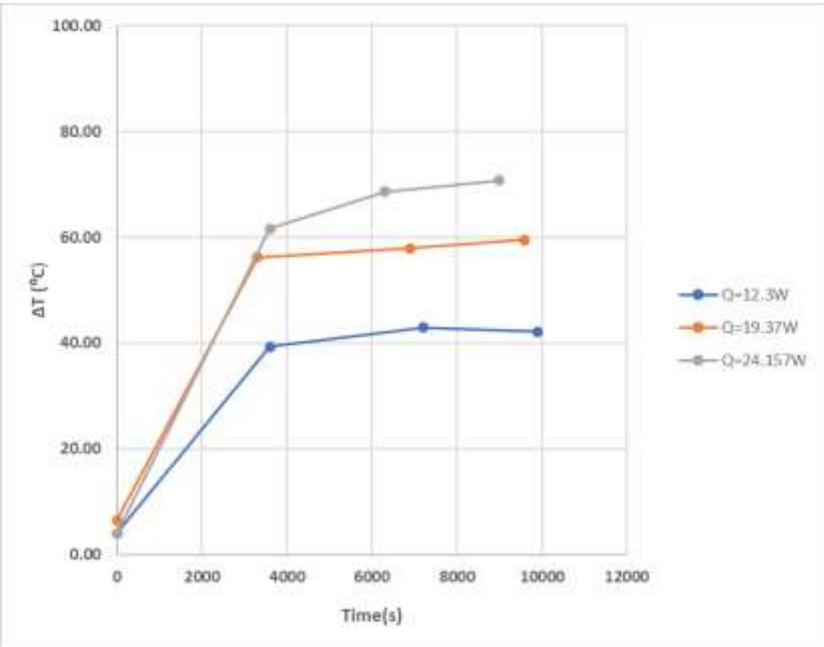


Figure 4.1: Time V/S Temperature Difference

Figure 4.1. Shows a temperature history for temperature difference ΔT showing how steady state is reached for finned heat sink. As the heat input of 12.3 W, 19.37 W, 24.157 W are kept varied in the experiment and allowed for steady state. It is observed from the fig as heat input increases there is an increase in the temperature and reaches to the steady state. The data's of the experiment are taken at steady state temperature for data reduction.

4.2 Effect of Temperature Difference on the Heat flux for base area

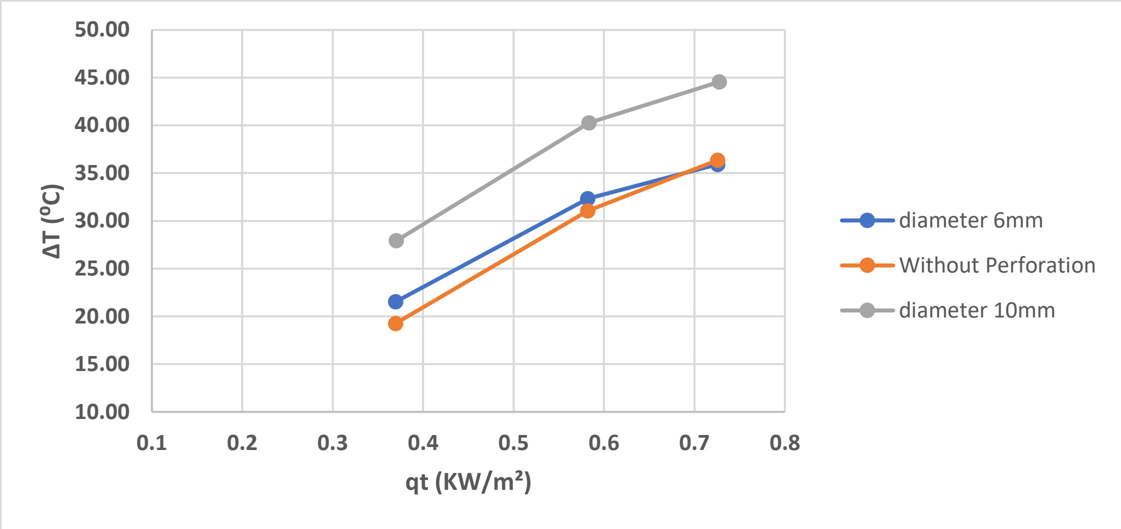


Figure 4.2: Temperature Difference V/S Heat Flux

Figure 4.2 shows temperature difference of the heat sink plotted against the corresponding heat flux values for finned heat sink for (base area). As heat flux increases there is an increase in the temperature difference ($\Delta T = Tw - Ta$) where, Tw is wall temperature and Ta is ambient temperature. The results are inline with the literature. It is observed from the figure 4.2 as perforation size (diameter) increases there is an increase in temperature. This is due to decrease in the surface area. The highest temperature difference is observed for highest diameter of 10mm.

4.3 Effect of Heat flux on the heat transfer Co-efficient for base area

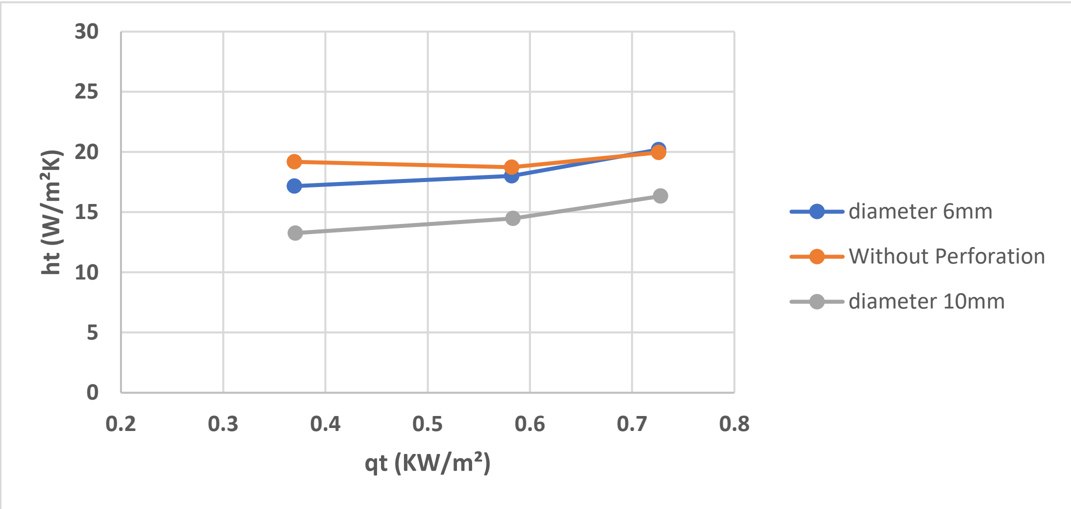


Figure4.3: Heat Transfer Co-Efficient V/S Heat Flux

Figure 4.3 shows heat Transfer Co-efficient h(Base area) of the heat sink plotted against the corresponding heat flux values for finned heat sink. As heat flux increases there is an increase in the heat transfer Co-efficient. The results are in line with the literature. It is observed from the figure 4.3 as perforation size (diameter) increases there is a decrease in temperature. This is due to decrease in the surface area. The highest heat transfer Co-efficient is observed for lowest diameter of 6mm.

4.4 Effect of Temperature difference on the Variation of heat transfer co-efficient for base area

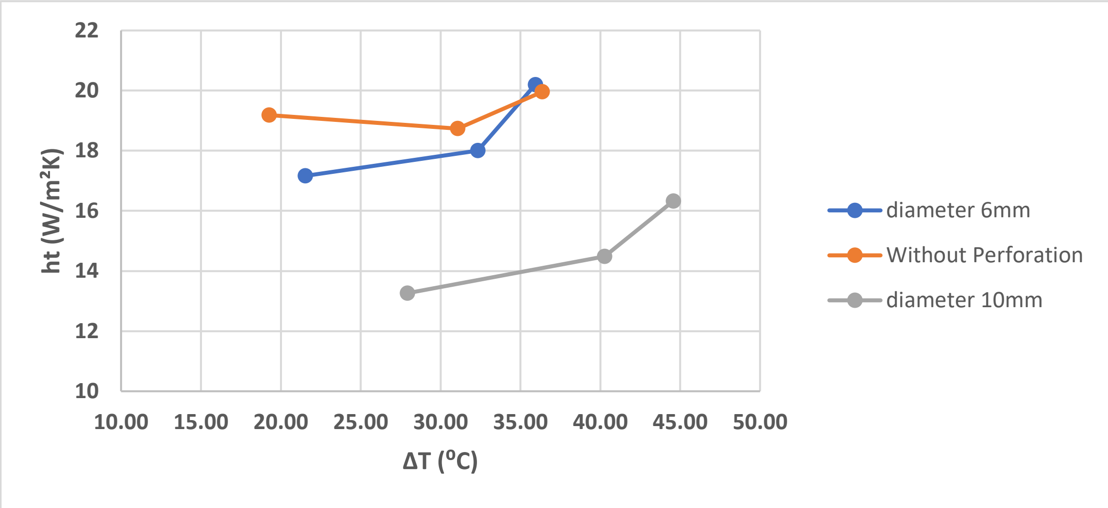


Figure 4.4: Heat Transfer Co-Efficient V/S Temperature Difference

Figure 4.4 Shows heat transfer Co-efficient h(Base area) of the heat sink plotted against the corresponding Temperature difference for finned heat sink. As temperature difference increases there is an increase in the heat transfer Co-efficient. The results are in line with the literature. It is observed from the figure 4.4 as perforation size (diameter) increases there is a decrease in heat transfer Co-efficient. This is due to decrease in the surface area. The highest heat transfer Co-efficient is observed for lowest diameter of 6mm.

4.5 Effect of Heat flux on the Resistance for base area

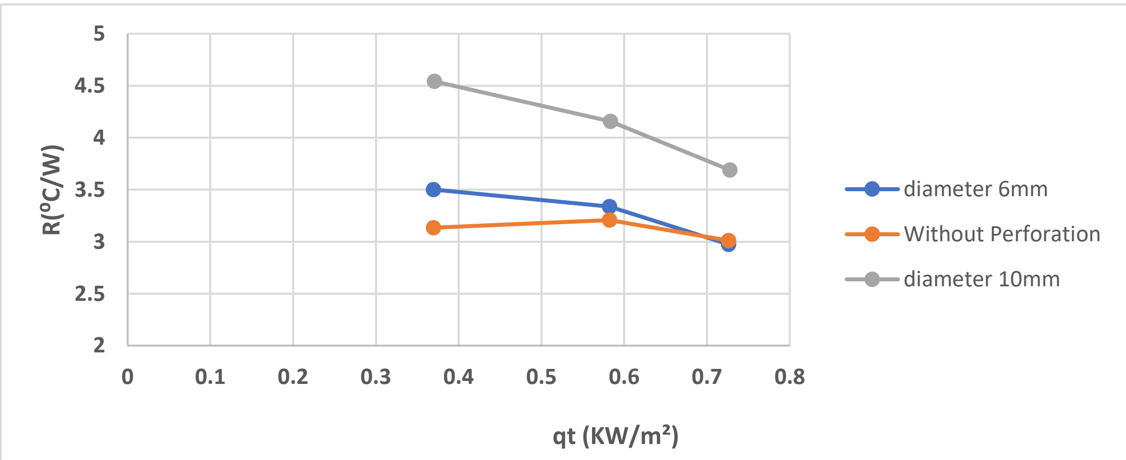


Figure 4.5: Resistance V/S Heat Flux

Figure 4.5 Shows resistance Offered h (Base area) of the heat sink plotted against the corresponding heat flux values for finned heat sink. As heat flux increases there is an decrease in the resistance. The results are in line with the literature. It is observed from the figure 4.5 as perforation size (diameter) increases there is a increase in resistance. This is due to decrease in the surface area. The highest resistance is observed for highest diameter of 10mm.

4.6 Effect of Heat flux on the Temperature difference for total area

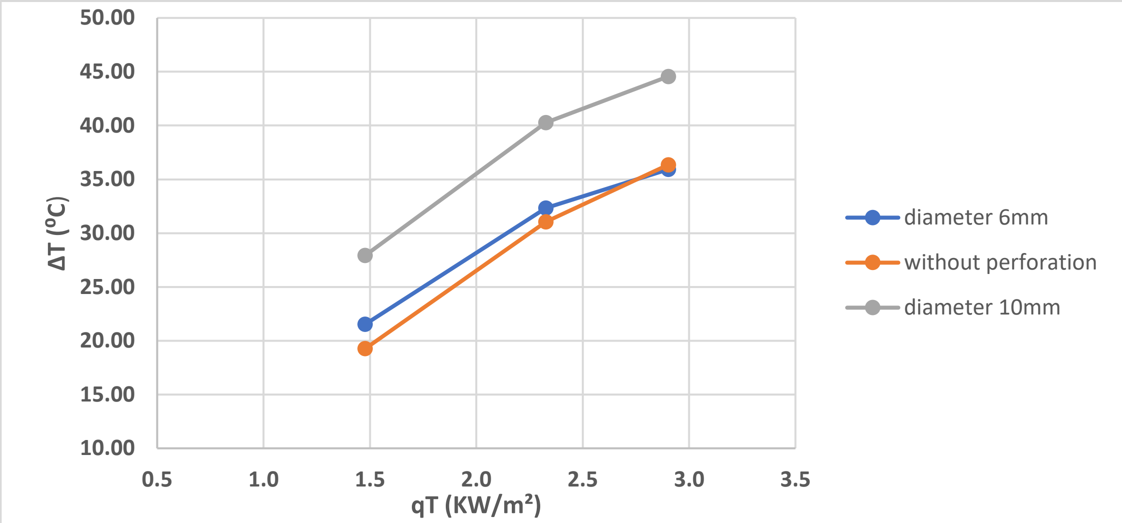


Figure 4.6: Temperature Difference V/S Heat flux

Figure 4.6 shows temperature difference of the heat sink plotted against the corresponding heat flux(total area) values for finned heat sink. As heat flux increases there is an increase in the temperature difference (ΔT = Tw - Ta) where, Tw is wall temperature and Ta is ambient temperature. The results are inline with the literature. It is observed from the figure 4.6 as perforation size (diameter) increases there is an increase in temperature. This is due to decrease in the surface area. The highest temperature difference is observed for highest diameter of 10mm.

4.7 Effect of Heat flux on the Heat transfer Co-efficient for total area

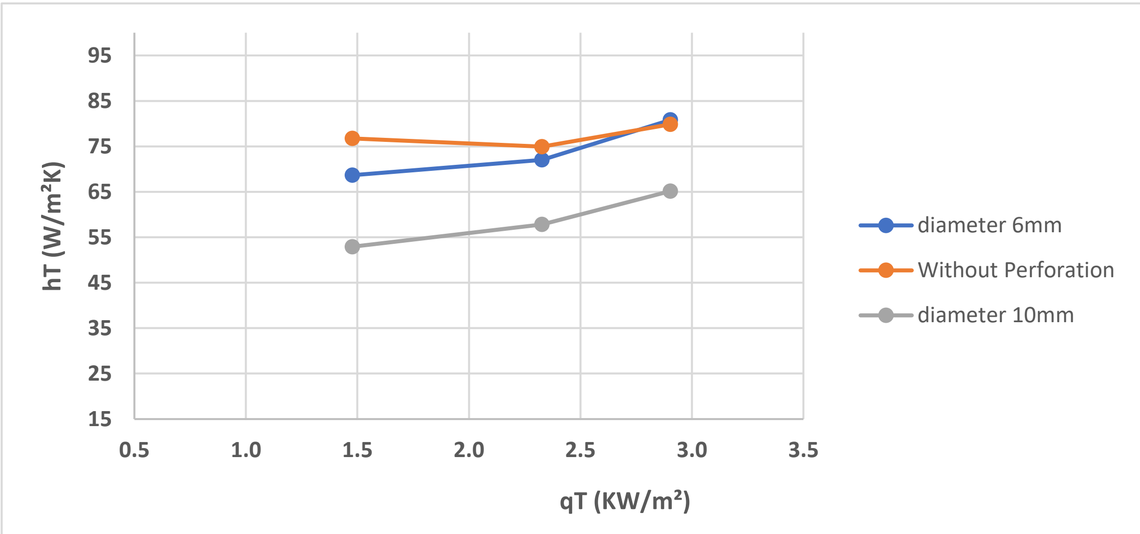


Figure 4.7: Heat Transfer Co-Efficient V/S Heat flux

Figure 4.7. Shows heat Transfer Co-efficient h(Total area) of the heat sink plotted against the corresponding heat flux values for finned heat sink. As heat flux increases there is an increase in the heat transfer Co-efficient. The results are in line with the literature. It is observed from the figure 4.7 as perforation size (diameter) increases there is a decrease in temperature. This is due to decrease in the surface area. The highest heat transfer Co-efficient is observed for lowest diameter of 6mm.

4.8 Effect of Temperature difference on the Heat transfer Co-efficient for total area

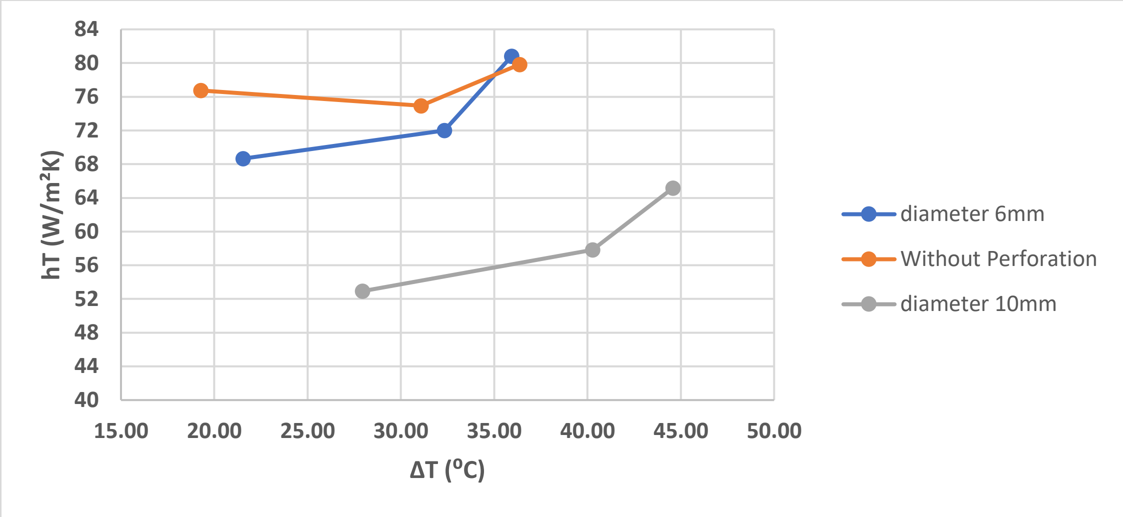


Figure 4.8: Heat Transfer Co-Efficient V/S Temperature Difference

Figure 4.8. Shows heat transfer Co-efficient h(total area) of the heat sink plotted against the corresponding Temperature difference for finned heat sink. As temperature difference increases there is an increase in the heat transfer Co-efficient. The results are in line with the literature. It is observed from the figure 4.8 as perforation size (diameter) increases there is a decrease in heat transfer Co-efficient. This is due to decrease in the surface area. The highest heat transfer Co-efficient is observed for lowest diameter of 6mm.

4.9 Effect of Heat flux on the Resistance for total area

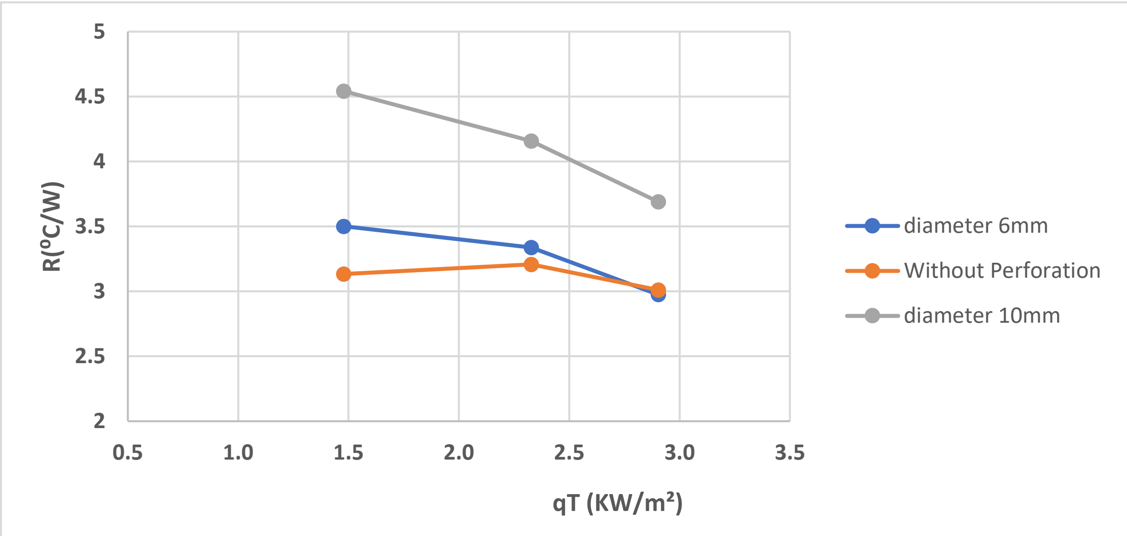


Figure 4.9: Resistance offered V/S Heat Flux

Fig.4.9 Shows resistance offered (Total area) of the heat sink plotted against the corresponding heat flux values for finned heat sink. As heat flux increases there is an decrease in the resistance. The results are in line with the literature. It is observed from the figure 4.9 as perforation size (diameter) increases there is a increase in resistance. This is due to decrease in the surface area. The highest resistance is observed for highest diameter of 10mm.

5. CONCLUSION

The project attempts to experimental investigation of heat transfer by natural convection in perforated heat sink. The CREO model was developed and formulated using CNC machine. The experimented conducted in two stages, with perforation and without perforation. The perforation provided on the fin space with two diameters of 6mm and 10mm and four heat input (12.3 W,19.37 W,24.157 W). The project attempts to investigate the effect of perforation on heat transfer rate. The following are the salient output points of the experiment as below:

- As heat flux increases there is an increase in the temperature difference.

- As heat flux increases there is an increase in the heat transfer Co-efficient.
- As temperature difference increases there is an increase in the heat transfer Co-efficient.
- As heat flux increases there is a decrease in the resistance.
- As perforation increases there is a decrease in the heat transfer.

6. FUTURE WORK

- The study can be extended for different geometry of perforation.
- The study can also be extended for heat transfer in stagnant immersed liquid.
- The study can be extended finite element analysis.

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