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EXPERIMENTAL ANALYSIS OF HEAT TRANSFER ENHANCEMENT USING FINS

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Abstract: Modern portable electronics have seen component heat loads increasing, while the space available for heat dissipation has decreased, both factors working against the thermal designer. Finned channels are modeled in order to optimize microstructure geometry and maximize heat transfer dissipation through convection from a heated surface. Six pin fin shapes – circle, square, triangle, ellipse, waveform and hexagon – are used in a staggered array and attached to the bottom heated surface of a rectangular channel and analyzed. Also, using square pin fins, different channel clearance over fins are investigated to optimize the fin height of the fins with respect to that of the channel. Fin width and spacing are investigated using a ratio of fin width area to the channel width. Fin material is then varied to investigate the heat dissipation effects. Triangular fins with larger fin height, smaller fin width, and spacing double the fin width maximizes the number of fins in each row and yields better performance. Correlations describing the Nusselt number and the Darcy friction factor are obtained and compared to previous ones from recent studies. These correlations only apply to short fins in the laminar regime. Completely understanding the effects of micro pin fins in a channel is essential to maximizing the performance in small scale cooling apparatuses to keep up with future electronic advancements.

Keywords: sinks, pitch fin type, fin efficiency.

I. INTRODUCTION

A heat sink is a colloquial term for a component or assembly that efficiently transfers heat generated within a solid material to a fluid medium, such as air or a liquid. Heat sinks are primarily used to remove unwanted heat from a device to keep it from overheating. Examples of heat sinks are the heat exchangers used in refrigeration and air conditioning systems and the radiator (also a heat exchanger) in a car. Heat sinks also help to cool electronic and optoelectronic devices, such as higher-power lasers and light emitting diodes (LEDs). Cell phones, computers, and MP3 players, are only a few devices which express the importance of electronics in today’s society. There is a drive to obtain the most efficient and powerful yet more compact electrical devices, and engineers are trying to increase the threshold that thermal effects have on the component material. Overheating of these electrical components are a concern as the temperatures reach values that threaten the proper functioning and their physical integrity. Currently, electrical components must sustain a low constant surface temperature to avoid overheating. The advancements in the electrical devices are limited to the absence of the efficient methods to remove the heat that is being generated. Small channels have been effective in removing heat through convection from the surface of a microchip. These channels act as heat exchangers at the nano, micro and miniscales. Forced and natural convection from fluids flowing through these channels can dissipate high surface temperatures. Nano, micro, and channels have a higher heat transfer surface area to fluid volume ratio than a conventional channel which enhances convection. The heat transfer coefficient increases as the hydraulic diameter’s size is reduced in the channel enabling an excellent cooling apparatus. Heat transfer theory helps explain practical aspects of how heat sinks work, and can also help to clear up common misconceptions and design mistakes. Approach air velocity, choice of material, fin (or other protrusion) design and surface treatment are some of the design factors which influence the thermal resistance, i.e. thermal performance, of a heat sink. One engineering application of heat sinks is in the thermal management of electronics, often computer CPU or graphics processors. For these, heat sink attachment methods and thermal interface materials also influence the eventual junction or die temperature of the processor(s). Theoretical, experimental and numerical methods can be used to determine a heat sink's thermal performance.

II. BASIC HEAT SINK HEAT TRANSFER PRINCIPLE

Heat sink is an object that transfers thermal energy from a higher temperature to a lower temperature fluid medium. The fluid medium is frequently air, but can also be water or in the case of heat exchangers, refrigerants and oil. If the fluid medium is water, the heat sink is frequently called a cold plate. To understand the principle of a heat sink, consider Fourier's law of heat conduction. Joseph Fourier was a French mathematician who made important contributions to the analytical treatment of heat conduction, as published in Fourier's law of heat conduction, simplified to a one-dimensional form in the *x*-direction, shows that when there is a temperature gradient in a body, heat will be transferred from the higher temperature region to the lower temperature region. The rate at which heat is transferred by conduction, q_k, is proportional to the product of the temperature gradient and the cross-sectional area through which heat is transferred. Consider a heat sink in a duct, where air flows through the duct, as shown in Figure 2. It is assumed that the heat sink base is higher in temperature than the air. Applying the conservation of energy, for steady-state conditions, and Newton’s law of cooling to the temperature nodes shown in Figure gives the following set of equations.

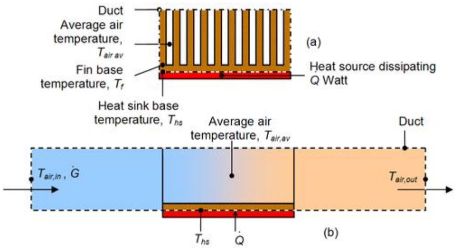

Figure.1 Sketch of a heat sink in a duct used to calculate the governing equations from conservation of energy and Newton’s law of cooling.

$$\dot{Q} = \dot{m}c_{p,in}(T_{air,out} - T_{air,in}) \quad (1)$$

$$\dot{Q} = \frac{T_{hs} - T_{air,av}}{R_{hs}} \quad (2)$$

where $$T_{air,av} = \frac{T_{air,out} + T_{air,in}}{2} \quad (3)$$

Using the mean air temperature is an assumption that is valid for relatively short heat sinks. When compact heat exchangers are calculated, the logarithmic mean air temperature is used. $\dot{m}$is the air mass flow rate in kg/s.

The above equations show that

- When the air flow through the heat sink decreases, this results in an increase in the average air temperature. This in turn increases the heat sink base temperature. And additionally, the thermal resistance of the heat sink will also increase. The net result is a higher heat sink base temperature.

The increase in heat sink thermal resistance with decrease in flow rate will be shown in later in this article.

- The inlet air temperature relates strongly with the heat sink base temperature. For example, if there is recirculation of air in a product, the inlet air temperature is not the ambient air temperature. The inlet air temperature of the heat sink is therefore higher, which also results in a higher heat sink base temperature.
- Therefore, if there is no air or fluid flow around the *heat sink*, the energy dissipated to the air cannot be transferred to the ambient air. Therefore, the heat sink functions poorly.
- Furthermore, a heat sink is not a device with the "magical ability to absorb heat like a sponge and send it off to a parallel universe".

Other examples of situations in which a heat sink has impaired efficiency:

- Pin fins have a lot of surface area, but the pins are so close together that air has a hard time flowing through them.
- Aligning a heat sink so that the fins are not in the direction of flow.
- Aligning the fins horizontally for a natural convection heat sink. Whilst a heat sink is stationary and there are no centrifugal forces and artificial gravity, air that is warmer than the ambient temperature ***always*** flows upward, given essentially-still-air surroundings; this is convective cooling.

III. FIN EFFICIENCY

Fin efficiency is one of the parameters which make a higher thermal conductivity material important. A fin of a heat sink may be considered to be a flat plate with heat flowing in one end and being dissipated into the surrounding fluid as it travels to the other. As heat flows through the fin, the combination of the thermal resistance of the heat sink impeding the flow and the heat lost due to convection, the temperature of the fin and, therefore, the heat transfer to the fluid, will decrease from the base to the end of the fin. This factor is called the fin efficiency and is defined as the actual heat transferred by the fin, divided by the heat transfer, if the fin has a uniform temperature. The equations for the fin efficiency have been given before, but are repeated below. Equations 6 and 7 are applicable for straight fins.

$$\eta_f = \frac{tanh(mL_c)}{mL_c} \quad (4)$$

$$mL_c = \sqrt{\frac{2h_f}{kL_f t_f}} L_f^{\frac{3}{2}} \quad (5)$$

To improve the fin efficiency of fins:

- Increase the fin thickness
- Increase the thermal conductivity of the fins

A. Spreading resistance

Another parameter that concerns the thermal conductivity of the heat sink material is spreading resistance. Spreading resistance occurs when thermal energy is transferred from a small area to a larger area in a substance with finite thermal conductivity. In a heat sink, this means that heat does not distribute uniformly through the heat sink base. The spreading resistance phenomenon is shown by how the heat travels from the heat source location and causes a large temperature gradient between the heat source and the edges of the heat sink. This means that the fins are at a lower temperature than if the heat source were uniform across the base of the heat sink. This non-uniformity increases the heat sink's effective thermal resistance.

To decrease the spreading resistance in the base of a heat sink:

- Increase the base thickness
- Choose a different material with better thermal conductivity

- Use a vapour chamber in the heat sink base. (Evaporation cools very effectively).

Fin arrangements

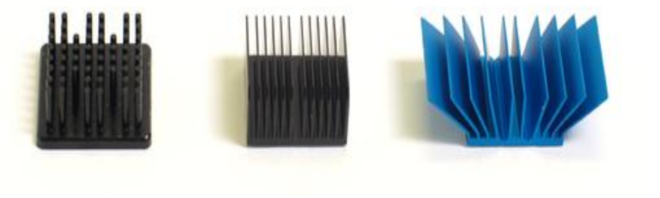

Figure.2 A pin fin, straight fin and flared heat sink types

A pin fin heat sink is a heat sink that has pins that extend from its base. The pins can be cylindrical, elliptical or square. A pin is by far one of the more common heat sink types available on the market. A second type of heat sink fin arrangement is the straight fin. These run the entire length of the heat sink. A variation on the straight fin heat sink is a cross cut heat sink. A straight fin heat sink is cut at regular intervals but at a coarser pitch than a pin fin type.

IV. DESCRIPTION OF TEST RIG SET-UP

A. Axial/ Radial Blower

The specifications of the axial air blower are as follows:
Power = 80 watt
Voltage: 230 Volt AC
Speed : 2350 rpm (variable)
Air discharge : 290 m3/hr

The axial blower is an single phase AC blower with axial entry of air and the radial outlet. The speed of the blower and thereby the discharge can be varied using an electronic speed regulator.

Fig.3 Axial Blower

B. Air Flow Channel:

The air flow channel is made from mild steel sheet, right hand end being a trapezoidal frustrum of cone(95 sq. x 75 sq.), the central part being an square pipe (75 x75), and the left end also being a trapezoidal frustrum of cone(95 sq. x 75 sq.). The central sq. pipe has an open end through which the heater and test model with thermocouples are introduced into air flow channel.

C. Air Flow Measurement.

The air flow measurement is done using an orifice and two manometer sets. One manometer set is connected across the test model whereas the other set is connected across the orifice.

D. Temperature Measurement:

Temperature measurement is done using thermocouples, uniformly located on the heating wall.

1. Heater Arrangement:

The heater arrangement is in the form of a plate heater , with the following specifications:
Power = 100 wats
Voltage: 230 Volt AC
CATALOGUE SERIAL No. 09
As per IS -3724.

The heater is mounted on an aluminium carrier plate , bolted to the base using M6 bolt is an insulator (pressed and reinforced asbestos sheet).

2. Test models

The test models of pin fins arrays uniformly distributed on the metal base ie, aluminium form the flow passage. the aluminium block used to form the test models has high conductivity (kf = 185 watt/m^{0}C). This block is milled on one side forming a array of small pin fins with side width (w) and height (δ). The empty space between the square pin fins becomes flow path. The porosity (ε) which characterizes the pin fin structure is calculated by,

$$\varepsilon = 1- (nw^2/WL)$$

Where;
N= The number of square pins
D= Gap between pins
W= Width of the Test model
L = length of test model

The following are four test models prepared:

The order of the magnitude of heat transfer enhancement obtained experimentally was similar to that obtained analytically. The heat transfer and pressure drop results for the pin fin heat exchanger were compared with the results for a smooth-pipe heat exchanger. It was found that by a direct comparison of Nu and Eu, no conclusion regarding the relative performances could be made. This is because the dimensionless variables are introduced for the scaling of heat transfer and pressure drop results from laboratory to large scale but not for the performance comparison. Therefore a literature survey of the performance comparison methods used in the past was also performed. It was found that all proposed methods in the literature offer only an approximate comparison of the performance of heat transfer surfaces. For new developments in heat transfer enhancement methods, it was considered that such methods would fail to predict the performance of new heat transfer surfaces. Hence in the present thesis a more consistent comparison method of the performance of heat transfer surfaces is proposed and its applicability demonstrated.

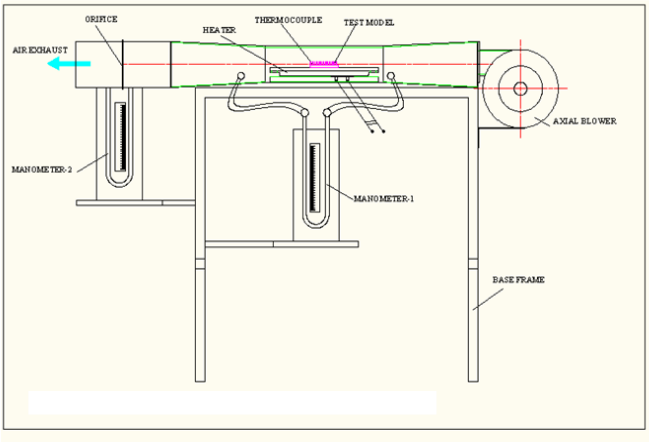

Figure.4 Experimental Set up

The test rig comprises of the following parts:
1. Axial/ Radial Blower: Blower with variable speed to adjust the air flow.
2. Venturi Type air flow chamber: This is developed for enhanced directed flow of air over the test fin structure, so also water tube -manometer arrangement will get the pressure drop across the fin structure, which can be used to determine nature of air flow above the fin structure.
3. Heater (Source): It is 230 Volt plate type 100 to 125 watt heaters.
4. Air flow measurement: Exhaust air flow measurement is done using orifice and water tube manometer tube.
5. Temperature measurement will be done using J-type thermocouples with multi-channel display.

The literature review is carried out in order to see the present research in this area status. Further review will be carried out for following purposes by referring journals like, International Journal of Heat and Mass Transfer, International Journal of Heat and Fluid flow, Pressure drop in heat sinks etc. There are almost no industrial fields in which heat exchangers are not applied. The design of the heat exchanger influences greatly the design of the entire system or process in which they are applied. Many factors influence the design of a heat exchanger, but the most important ones are the heat transfer rate, pumping power required to run the heat exchanger, heat exchanger volume required, heat exchanger weight and heat exchanger production costs. Depending on the application, some of the above factors may have priority but in general the first factors that have to be considered are heat transfer rate, power input and heat exchanger volume. With the exception of a few cases, usually in all kinds of processes high heat transfer rate and small pressure drop within a small heat exchanger volume are required. Particular care in consideration of the last three factors is required for heat exchangers containing gas streams or gas and liquid streams separated by solid walls. In any heat exchanger form, the heat is transferred by all three basic forms: conduction, convection and radiation simultaneously. Otherwise the heat transfer surface area increase is achieved by a dense population of the bare surface with such fins and by selecting thin and long fin forms. Similar effects can be expected also in pin fin arrays. Hence they may be considered as a special kind of interrupted fins, although they are not obtained by cutting of continuous fins such as in the case of strip or louvered fins. The analytical and experimental study of the heat transfer enhancement obtained by employing pins was the first objective of the present work. The Reynolds number, effectiveness are the important parameters which decides the success of any experimentation work as both parameters are opposite to each other. The Reynolds number shows the percentage increase in heat transfer enhancement when fins are placed inside a set up due to increase in heat transfer coefficient by comparing it, with different fins. Contradictory to it is when fins are placed inside the set up the friction gets produced inside due to which there is drop in pressure hence the desire increase in heat transfer coefficient is offset by pressure drop. Hence, the inserts should be designed in such a way that there pumping cost should get offset by heat enhancement. The thermal characterization and optimization points were found experimentally. The secondary goal was to find a theoretical methodology that would accurately predict both the optimization point for a given space as well as the performance of the solution. The chosen methodology did accurately predict the optimization point; however, it predicted better performance of the system on average by 40%. Conclusion thus obtained from testing of various fin structures and experimentally done as to effectiveness of individual fin structure over other as regards to Overall heat transfer coefficient , Heat transfer ability (watt/min), Obstruction to air flow, etc and recommendations will be made as to application of the above structures to this experimental setup.

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