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Experimental Study for Heat Transfer Analysis in Electronic Circuit along with Inclined Blocks Using Sharp Edged Wavy Plate

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Abstract

An experimental study of forced convection for air flowing through printed circuit board under turbulence flow condition has been considered. The importance of heat transfer enhancement has gained greater significance in areas such as microelectronic cooling, especially in central processing units, macro and micro scale heat exchangers, gas turbine internal airfoil cooling, fuel elements of nuclear power plants, and bio medical devices. A tremendous amount of effort has been devoted in developing new methods to increase the heat transfer from finned surface to the surrounding flowing fluid. The present work suggests a way to enhance the electronic circuit cooling using sharp edged wavy plate and inclined blocks.

Keywords: *Heat transfer, Forced convection, Printed circuit board, Channel flow*

1. Introduction

Heat transfer analysis in channels formed by a parallel PCB is challenging. The problem is complicated because of complex geometry of the PCB assembly and different thermal properties of the board materials. Effective cooling of electronic components is crucial to maintain their normal operation and hence reliability. A Printed Circuit Board (PCB) is used to mechanically support and electrically connect electronic components using conductive pathways, tracks or signal traces etched from copper sheets laminated onto a non-conductive substrate. It is also referred to as printed wiring board (PWB) or etched wiring board. A PCB populated with electronic components is a printed circuit assembly (PCA), also known as a printed circuit board assembly (PCBA). PCBs are inexpensive and highly reliable. The PCB's has got its application in computers, Lap-Tops, T.V., Radio, Telephones, Handy Cams, Daily Usage Home Appliances and Industrial Components. Presently almost every stream uses PCB's directly or indirectly to make the system automatic, faster, user friendly and no doubt compact to increase portability. Compactness technology for the electronic devices (such as semiconductor technology) increases the miniaturization of components. As electronic components are made smaller or miniaturize, the amount of heat that is to be dissipated per unit volume of a device increases dramatically. For example, the peak heat fluxes in a recent computer circuit are 10 times greater than those in an older computer.

Fig. 1 Printed Circuit Board Assembly

1.1 Necessity for Extraction of Heat from Electronic Devices

Many modern electronic devices are made up of heat producing components mounted on closely-spaced circuit boards, as typified by the computer circuit. The electronic components act as local heat sources, and the heat flux dissipated into the cooling fluid is highly non uniform.

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Heat being generated by the electronic devices and the junction temperature of the electronic devices being higher and the insufficient extraction of heat from the electronic components, affects their performance, accuracy of the results needed, working life time etc. Thus the extraction of heat from the electronics components to maintain them at particular temperature has become an important aspect of study. The failure rate of the electronic device has been statistically corrected to be proportional to the exponential of the electronic device junction temperature. The heat dissipation capability of an electronic system has become one of the primary limiting factors for circuit miniaturization. Effective cooling of electronic components is crucial to maintain their normal operation and hence reliability. It is desirable that the heat generated per unit volume of a device can be dissipated to the cooling fluid rapidly to avoid its temperature from rising significantly, which may lead to malfunction and break down of the entire device.

2. Literature Review

A lot of research has been carried out on the use of passive vortex generators in the heat transfer enhancement. Leung et al. [1] developed the numerical solution of steady-state forced convection, for air flowing through a horizontally oriented simulated printed circuit board (PCB) assembly under laminar flow condition. The considered assembly consisted of a channel formed by two parallel plates. The upper plate was thermally insulated, whereas the bottom plate was attached with uniformly spaced identical electrically heated square ribs perpendicular to the mean air flow. The bottom plate was used to simulate the PCB, and the ribs with heat generation were used to simulate the electronic components. A second-order upwind scheme was adopted in the calculation and a very fine mesh density was arranged near the obstacle and channel surface to achieve higher calculation accuracy. Abbassi et al. [2] numerically investigated the superposition of Von Karman street and convective cells in a horizontal plane channel containing a triangular prism and the channel was heated from below. Attention was focused on the effect of the presence of the triangular prism on the heat transferred from the hot wall to the flow. The Control Volume Finite Element Method (CVFEM) was used. It was observed that the presence of the obstacle considerably enhanced the heat transfer from the hot wall to the flow. Yang [3] proposed a concept of vortex generator to enhance the heat transfer of electronic devices. An oscillating bar was set in a channel with heated obstacles. The oscillating bar serves as an oscillating vortex generator to actively generate vortices. The behavior of the oscillating bar and flow was coupled, and the variations of the flow and thermal fields were classified into a type of moving boundary problem. An arbitrary Lagrangian–Eulerian kinematic description method was employed to describe the flow and thermal fields, and a Galerkin finite element method was used to solve the governing equations. The effects of Reynolds number, oscillating speed, and oscillating amplitude of the bar on the flow and heat transfer were examined in detail. The results indicated that vortices induced by the oscillating bar were actively and largely formed around the channel and migrate downstream. As the bar moves upward, the vortices around the top wall of the channel push the low-temperature and high-speed core flow toward the top surfaces of heated obstacles and induce the vortices within the grooves to eject into the core flow. These flows assisted the heat transfer from heated obstacles. As the bar moves downward, the vortices around the top wall of the channel push the core flow toward the grooves and induce new vortices to form around the top surfaces of the heated obstacles. These flows may prevent the heat transfer from the heated obstacles. In addition, the heat transfer rate was increased when the oscillating amplitude of the bar was increased, but it was not directly proportional to the oscillating speed of the bar. With executed apparatus the overall heat transfer from heated obstacles was augmented greatly. Sikka et al. [4] investigated the effects on heat transfer by geometrically rearranging the surface area of a finned heat sink. Novel heat sinks with fluted and wavy plate fin configurations were designed and fabricated together with conventional longitudinal-plate and pin fin heat sinks. The thermal performance of the novel and conventional heat sinks was measured and compared for the horizontal and vertical base plate orientations under natural and low-velocity forced convection conditions. Tsay et al. [5] numerical analyzed the performance of mixed convection in a horizontal duct with two heated blocks mounted on the bottom plate and baffles arranged on the up plate. The effects of the dimensionless height of baffle Hb, the dimensionless distance between the block and baffle D, and the number of baffle N on the flow structure and heat transfer characteristics were investigated for the system at various Reynolds number Re and Gr/Re^2. With the two baffles installed at D1 = 0 and D2 = 0. The results shows that the maximum augmentation in the average Nusselt number of the second heated block was exceeded 320% for Hb1=Hb2=0.4, Pr = 0.7, $100 \leq Re \leq 1000$, and $0 \leq Gr/Re^2 \leq 10$, while the maximum augmentation was about 130% for the first heated block. Chung and Tucker [6] numerically studied the unsteady heat transfer enhancements in grooved channel and sharp 180° bend flows, especially relevant to electronic systems. Prior to above to find the most efficient numerical approaches, performances of various pressure corrections, convective and temporal schemes were studied. Alawadhi [7] numerically studied the heat transfer enhancement using a sinusoidal plate in a channel containing heated blocks. The considered assembly of a channel was formed by two plates with heated blocks attached to both internal walls and a sinusoidal plate installed at the centerline of the channel. The sinusoidal plate enhanced heat transfer from the blocks through the modification of the flow pattern. The effect of the Reynolds number, waviness of the sinusoidal plate, and blocks spacing on the Nusselt number and maximum temperature of the blocks was investigated. Chomdee and Kiatsiriroat [8] experimentally investigated the heat transfer enhancement by delta winglet vortex generators in air cooled staggered array of rectangular electronic modules. The winglet vortex generators were placed in front of 3×5 (rows and columns) modules with 20° attack angle. Each module had dimensions of 1.8×5.4×0.6 cm and each one generates a heat at 2.5W. Kumar and Dalal [9] studied computationally on laminar flow and heat transfer past a triangular cylinder placed in a horizontal channel (For the Range $80 \leq Re \leq 200$ and Blockage ratio $1/12 \leq \beta \leq 1/3$). A second-order accurate finite volume method with non staggered arrangement of variables employing momentum interpolation for the pressure-velocity coupling was used. Hosseini et al. [10] numerically investigated the mixed convection heat transfer and the fluid flow in the Poiseulle–Benard Channel with wall-mounted obstacles. The UTFN [Nourollahi 2007] code was used to solve the momentum and energy equations. The result had shown that with the increase of the wall-mounted obstacles over the channel wall, the Nusselt number increases as compared to the simple channel. On the other hand, the number of the obstacles was not directly proportional Nusselt number. Though the maximum Nusselt number was achieved by the optimize number of the obstacles. Paisarn [11] numerically investigated the heat transfer and flow distributions in the channel with various geometric configurations of wavy plates under constant heat flux conditions. To solve the turbulent model, Finite Volume Method with the structured uniform grid system was used. Effects of geometric configuration of wavy plates, wavy plate arrangements, and air flow rates on the temperature and flow developments were considered. R.K. Ali [12] experimentally investigated the heat transfer enhancement by perforation in air cooling of two in-line rectangular heat sources module. Two separation distances between the heat sources were investigated at $s/L = 0.5$ and 1.0.Cardone and Panelli [13] experimentally investigated the effect of periodic patterns of protrusions (ribs) on the free-convection heat transfer in a vertical plate with uniform heat flux rate boundary condition. The result shows that the use of periodic pattern of ribs placed on a vertical flat plate in natural convection improves convective heat transfer to its maximum. The above literature survey shows that the numerous experimental and theoretical studies have been performed to enhance heat transfer in the channel flow and on electronic circuit board; however there is still a room to discus.

3. Problem Formulation

Literature review shows that many experimental and theoretical attempts have been made to improve the heat transfer enhancement in electronic circuit boards. No attempts so far has been made using a sharp edged wavy plate to enhance the heat transfer in an electronic circuit board in a turbulent flow. In the present study attempt will be made to suggest a new method for heat transfer enhancement using sharp edged wavy plate along with inclined blocks for heat transfer enhancement in Printed circuit Board.

4. Experimental Set Up

A schematic diagram of the experimental apparatus is presented in Figure 2. The experimental apparatus consist of a rectangular duct which was made up of plywood having the total length of 1750 mm. It consist of four parts, first part is the inlet section having length of 500 mm, width 200 mm, height 120 mm. A straightener is used in the inlet section up to a length of 200 mm to minimize the turbulence in the air and to keep a uniform air flow before entering the test section. A port is made in the top part of the inlet section for the measurement of velocity by hot wire anemometer. Second part of the duct is the test section having the overall length of 600 mm, width 200 mm, height 120 mm. Test section consist of a rectangular plate made up of aluminum , having dimension of 300x150x6 mm. The rectangular inclined blocks are mounted on the test plate which simulates the electronic devices mounted on the PCB and a sharp wavy edge plate has been inserted as shown in Figure. The AC power supply was the source of power for the plate type heater with a capacity of 400 W used for heating the plate and the inclined blocks of test section only in order to maintain a uniform surface heat flux. Air as the tested fluid in both the heat transfer and pressure drop experiments, was directed in to the system by a blower. The operating speed of the fan could be varied by using a regulator to provide the desired flow rates. The flow rate of air in the system can be measured by a hot wire anemometer (Testo-405). In order to measure the temperature distributions on the plate, six thermocouples wires of k- type are fitted to the plate at equal distance from the sides of the plate. The k -type thermocouples were installed by using the thimbles and screwing them to the plate. To measure the inlet and outlet temperature of air hot wire anemometer (Testo-405) is used. The thermocouples voltage output is fed up in to the k-type multichannel indicator. A variac is used to control the

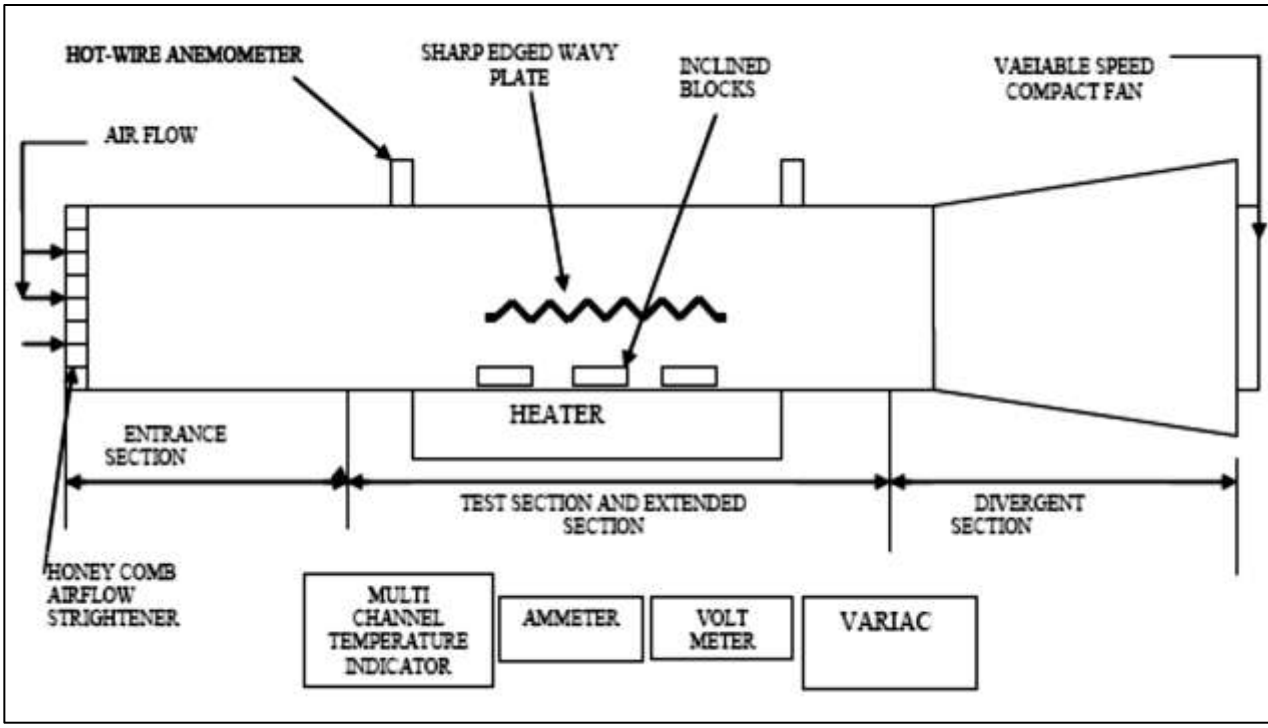

Fig.2 Schematic Diagram of Experimental Apparatus

wattage of the heater and various readings are observed at different values of current and voltage. Third part of the duct is the extended section having dimension of 200x200x120 mm, on the top of which the hot wire anemometer is placed to measure the outlet velocity of the air and to measure the temperature of the outlet air. Fourth part of the test section is the divergent section having an angle of 8^o and of 450 mm length. The end of the divergent section has the square part of 230x230 mm which consists of a blower of 200 mm in diameter along with a capacity of 360 cubic feet per minute. The pictures of the experimental set-up is shown in Fig.2

5. Equations

The components of experimental apparatus and instruments were fixed and tested as shown above in pictures. The velocity of the air was controlled through regulator at a desired value. The heat flux was controlled by the use of variac. The heater power was fixed at certain value until the surface temperature attained a steady state, then the value of heat transfer coefficient was calculated by using Newton's Law of cooling i.e.

Q_{conv} = h x A x(Ts-T_b) =VI (wattage given to heater) (1)
Where, T_s= Average of surface temperature
T_b=bulk Temperature $(T_{o,a} + T_{i,a})/2$ (2)
h= convective heat transfer coefficient

Nusselt number:

$Nu = hD_h/k$ (3)
Where, D_h is the hydraulic diameter of channel
k=conductivity of air at bulk temperature

Reynolds number:

Re $= UD_h/v$ (4)
Where, U is the mean velocity of air in the channel.
v is the kinematic viscosity of air at bulk temperature.

6. Discussion and Conclusion

PCBs are often exposed to high temperature during operation. With high temperature significant thermal stresses may develop and cause warpage because of the different coefficient of thermal expansion of the copper lines and the substrate. The warpage in boards could cause imperfect soldering which could cause detachment of components from the circuit board in other sense high temperature leads to dimensional instability of the printed circuit boards. This problem could eventually lead to the failure of electronic device. This experimental setup is an innovative design to enhance the heat transfer in an electronic circuit board. The use of wavy plate and the blocks in inclined manner causes the flow disturbances, re-circulation or/and swirl flows and hence the thinning of thermal boundary layer hence causing the increase in the heat transfer. This can reduce the thermal stresses and the size of the circuit board for the same heat transfer hence causes the miniaturization of the equipment. Further the study can be carried out to find the heat transfer augmentation using the above said device and compare it with conventional system. The study can be further performed to study the modification in flow structure with the use of wavy plate. Further the percentage reduction in size of the PCB can be calculated. In end it is an innovative setup for reducing the size of the electronic circuit.

Nomenclature

Re	Reynolds number
A	Area of plate, m^2
D_h	Hydraulic Diameter of duct, m
Q	Heat transfer, W
V	Voltage supplied to heater, volts
I	Current, amp
Nu	Nusselt number
h	Heat transfer coefficient ,W/m^2k
Ts	Average surface temperature of plate,°c
T_b	Bulk temperature of air, °c
U	Mean air velocity, m/s
k	conductivity of air , W/mK
H	height of channel, mm
W	width of plate,mm
h	height of block,mm
w	width of block,mm
l	distance of sharp edged wavy plate from base plate,mm

Subscripts

i	inlet air temperature , °c
o	outlet air temperature , °c
conv	convection
s	plate surface
b	bulk

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