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# Multi-mode Heat Transfer Charcterstics of a Rectangular Heat Sink with Uniform Heat Generation in its Base – Numerical Approach

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**Abstract -** *The present work describes the important results of the problem of combined conduction, convection and radiation from a heat sink with internal heat generation. The governing equations of the heat sink are obtained by relevant energy balance between the heat generated, conducted, convected and radiated and those attained partial differential equations are converted into algebraic form using Finite Difference Method. The obtained algebraic equations have been solved by Gauss Siedel iterative technique with stringent convergence criterion and a C code has been written for the above purpose. Grid size has been optimized by conducting a grid convergence test for the fixed inputs. Height of the fin has been optimized by testing for different heights and their effect on peak board temperature. An extensive parametric study has been carried out to elucidate the effect of various parameters on local temperature profile and maximum sink temperature.*

***Key Words***: *Internal heat generation; Heat transfer coefficient; Thermal conductivity; Temperature distribution; Radiation affect*

## 1. INTRODUCTION

A heat sink is a passive heat exchanger which transmits the heat, produced by an electronic or a mechanical device to a fluid medium (air or liquid), where it will be exhausted away from the device, where the peak temperatures are acquired. The basic purpose of a heat sink is to maintain the sink temperature below the maximum permissible temperature specified by the device. There are many modifications to improve rate of heat transfer on basis of heat sink. i. To increase the convection heat transfer coefficient (h) ii. To increase surface area. The alternate method is to increase surface area by attaching to extended surfaces called fins. In various applications heat from the fins is dissipated by both natural and forced convection and radiation. It is observed that radiation contributes up to 20% of total heat dissipation.

There has been continuous research on improving heat transfer rate of heat sink with multimode heat transfer. Early analysis had done by reiyu and huang [15] carried out silicon performance of micro channel heat sink using copper and pure water as Nano fluids, micro channel heat sink performances for different widths. Dharma Rao and Govinda Rao [14] had performed numerical simulation on heat transfer from a horizontal fin array by natural convection and radiation; they found that decreasing the spacing of the fin increases the heat transfer rate with high radiation affect. Tsung and Reyu [13] had performed the analysis on heat sink by using copper-water and carbon nano tube water as the coolants and it was originated that nano fluids diminish the temperature on the base of the heat sink. Chen [12] had performed analysis on heat transfer in micro channel heat sink by forced convection. Mohammed and shuiab [11] had carried out numerical analysis on Heat transfer in rectangular micro channels heat sink using alumina–water ($Al_2O_3$-$H_2O$) Nano fluid. Later Lee and Yook [10] had done experimental and numerical investigation on natural convection around a radial heat sink of horizontal circular base and rectangular fins with increasing number of fins, fin length and fin height and obtained an effective low heat sink temperature. Gunnasegaran and shuiab [9] had carried out numerical simulation on wavy micro channel heat sink with rectangular cross-section with various wavy amplitudes vary from 125 to 500 µm. Hwan and Lee [8] performed numerical analysis on effect of radiation in a radial type heat sink by taking into account natural convection and radiation by varying emissivity, had noticed that the maximum radiation benefaction on heat transfer was 27% and thermal heat transfer coefficient was increased by 12.3%, and thermal resistance had lowered by 8.7%. Tari and Mehdi [7] had investigated numerical analysis on natural convection heat transfer from inclined plate-fin heat sinks which are heated from the back with a heater are obtained from finite volume computational fluid dynamics simulations. Bin and Baik [6] had carried out analysis experimentally and numerically on heat transfer for natural convection on chimney type radial heat sink, effects on the heat sink thermal performance were looked over for orientation angle with respect to gravity and found that chimney-based heat sinks oriented at ($0° and 45°$) have more desirable thermal performance than which oriented at ($135° and 180°$), while which oriented at 90°has the poor thermal performance. Byon and Jeon [5] had performed numerical investigation on natural convection heat transfer around a radial heat sink with a perforated ring with the effects of perforation number. Shen and Jin [4] had performed analysis numerically on natural convection heat transfer along vertical cylinder heat sinks with longitudinal fins based on CFD method. Seyed and Ranjbar [3] had conducted Experimental and numerical investigation of circular minichannel heat sink having dimension of 60 mm in length and total height of 16 mm. Han and Ren [2] had carried out experimental and numerical analysis on heat transfer properties of liquid cooling heat sink with micro pin fins. Seyed and Hosseini [1] had conducted experimental analysis on cooling performance of mini channel heat sink by using nanofluid and obtained that heat transfer coefficients found to be increased with increase in volume flow rate. These perceptions incited the creators to consider the hotness move to the liquid in a restricted walled in area from the balances and to incorporate the radiation method of hotness move in their examination.

Thus the issue on multimode heat move to the hotness sink is hypothetically handled by presenting the idea of interior hotness age to the hotness sink by the overseeing conditions of the hotness sink are acquired by pertinent energy balance between the hotness created, led, convected and emanated and those accomplished incomplete differential conditions are changed over into mathematical structure utilizing Finite Difference Method. The got mathematical conditions have been tackled by Gauss Siedel iterative method with severe combination model and a C code has been composed for the above reason. Heat move by radiation is additionally viewed as in the examination.

## 2. DESCRIPTION OF THE PROBLEM

The base of the heat sink consists of L×B, in x and y directions respectively. And the fins are attached on the base of the heat sink then the directions x, y, z are to be considered for the total heat sink where the pitch and height of the fins are also acts into play. The thermal conductivity of the aluminium material is (k), the rate of volumetric heat generation is ($q_v$), the surface emissivity of the heat sink is (ε) and the convection heat transfer coefficient is (h). The cooling medium is air at an ambient temperature( $T_\infty$).

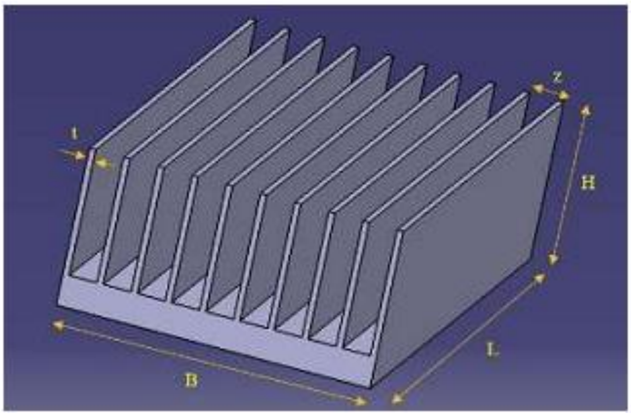


Fig. 1 Geometry of uniformly heated rectangular heat sink with straight fins along with specifications

The governing equations for the distribution of temperature in the entire computational field are achieved through energy balance of heat generation, conduction, convection and radiation. With concern to the temperature dissemination along the interior nodes of the computational field, by executing energy balance to all interior nodes in individual, belonging to the heat sink region achieves,

$$Q_{x\,in.} + Q_{y\,in.} + Q_{gen.} = Q_{X+\Delta X} + Q_{y+\Delta y} + Q_{conv.} + Q_{rad.} \quad (1)$$

the governing equation for all the interior nodes, upon energy balance, turns out to be:

For base of the heat sink:

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{q_v}{k} - \frac{h}{k}\left(T_{i,j} - T_\infty\right) - \frac{\sigma\varepsilon}{k}\left(T_{i,j}^4 - T_\infty^4\right) = 0 \quad (2)$$

For the fins:

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial z^2} - \frac{2h}{k*\Delta y}\left(T_{i,z} - T_\infty\right) - \frac{2\sigma\varepsilon}{k*\Delta y}\left(T_{i,z}^4 - T_\infty^4\right) = 0 \quad (3)$$

With favour to the temperature distribution along the boundaries of the computational field, by performing energy balance on element along the left boundary (other than corners), in actual, belonging to the heat sink region, which gets the following equation as

$$Q_{x\,in.} + Q_{gen.} = Q_{x+\Delta x} + Q_{y\,cond.} + Q_{conv.} + Q_{rad.} \quad (4)$$

By substitution of the well-suited expressions for various terms in the above equation and simplifying, the non-linear partial differential equation attained is:

$$\frac{\partial^2 T}{\partial x^2} + \frac{2}{\Delta y}\frac{\partial T}{\partial y} + \frac{q_v}{k} - \left(\frac{h}{k} + \frac{2h}{k\Delta y}\right)\left(T_{i,j} - T_\infty\right) - \left(\frac{\sigma\varepsilon}{k} + \frac{2\sigma\varepsilon}{k\Delta y}\right)\left(T_{i,j}^4 - T_\infty^4\right) = 0$$

Similarly, for the fins we get:

$$\frac{\partial^2 T}{\partial z^2} + \frac{2}{\Delta x}\frac{\partial T}{\partial x} - \left(\frac{2h}{k*\Delta z} + \frac{2h}{k*\Delta x}\right)\left(T_{i,z} - T_\infty\right) - \left(\frac{2\sigma\varepsilon}{k*\Delta z} + \frac{2\sigma\varepsilon}{k\Delta x}\right)\left(T_{i,z}^4 - T_\infty^4\right) = 0$$

With regard to the temperature distribution along the corners of the computational field, by performing energy balance on element along the bottom left corner quarter element in particular, belonging to the heat source region, one gets

$$Q_{gen.} = Q_{x\,cond.} + Q_{y\,cond.} + Q_{conv.} + Q_{rad.}$$

By substitution of the compatible expressions for various terms in the above equation and simplifying, the non-linear partial differential equation obtained is:

$$\frac{2}{\Delta x}\frac{\partial T}{\partial x} + \frac{2}{\Delta y}\frac{\partial T}{\partial y} + \frac{q_v}{k} - \left(\frac{h}{k} + \frac{2h}{k\Delta x} + \frac{2h}{k\Delta y}\right)\left(T_{i,j} - T_\infty\right) - \left(\frac{\sigma\varepsilon}{k} + \frac{2\sigma\varepsilon}{k\Delta x} + \frac{2\sigma\varepsilon}{k\Delta y}\right)\left(T_{i,j}^4 - T_\infty^4\right) = 0$$

Similarly, for the fins:

$$\frac{\partial^2 T}{\partial y^2} + \frac{2}{\Delta x}\frac{\partial T}{\partial x} + \frac{2}{\Delta z}\frac{\partial T}{\partial z} + \frac{q_v}{k} = 0$$

Same technique is applied for achieving the temperature of the remaining boundaries as well.

## 3. SOLUTION METHODOLOGY AND PARAMETER LIMIT

The nonlinear partial differential equations governing equations are considered for the temperature distribution in the entire computational domain. The governing equations of each element are converted into algebraic equations by using 1st and 2nd order accurate finite difference analogues. Full relaxation has been used on temperature during iterations, while a convergent criterion of $10^{-5}$ has been imposed to terminate the iterations. A computer code in C++ has been written to solve the problem. The ranges of different independent parameters concerning the problem were fixed after some basic considerations. The Length (L) and the width (B) of the heat sink are taken to be 20 cm and 10cm respectively. The height of the fin (H) is fixed to be 30mm and pitch of the fin considered as 5mm. The present problem solved with the range of independent parameters with the surface emissivity (ε) of the heat sink is varied from 0.05 to 0.8. The thermal conductivity (k) of the heat sink are varied by k=55W/m-k, 130 W/m-k, 167 W/m-k and 386 W/m-k are considered. The convection heat transfer coefficient (h) is varied from 5 W/m$^2$ K to 100 W/m$^2$ K. The above values of h are corresponding to the free convection limit to the forced convection limit. The rate of volumetric heat generation ($q_v$) is fixed with the value of 1000000 W/m$^3$. The ambient temperature ($T_\infty$) of the cooling medium (air) is taken to be 303K.

## 4. RESULTS AND DISCUSSION

4.1 Grid Independent Test:

Grid independent analysis had performed for five phases, with both free and forced convection by considering the input parameters fixed at $q_v$=1000000 W/m$^3$, k=0.25 W/m-K, ε=0.5 and h=5 W/m$^2$K. In 1st phase the number of nodes in vertical x-direction (M) =11 and nodes in horizontal y-direction (N)=11 are chosen, where elemental lengths in x and y-direction are $\Delta x = 0.02, \Delta y = 0.01$. The maximum heat sink temperature ($T_{max.}$) is found and further in phase-2 M is increased to 31 from 11 and N is increases from 11 to 21 and it is noticed that $T_{max.}$ decreases by 0.6%. In phase-3 the nodes in x-direction is taken as 51 and in y-direction as 31 and it is found that maximum temperature is changed by 0.8%. Similarly, in phase-4, M is increased to 81 and N to 41 and it is seen that $T_{max.}$ varies with 0.5%, it was observed that there is not much effective decrease in the heat sink temperature and later in phase-5 of study the number of nodes of M is taken as 101 and N is fixed at 51, where elemental lengths$\Delta x = 0.001$, $\Delta y = 0.001$and examined that the grid convergence occurred at this particular values of M and N with decrease in temperature by 0.01%. In summary, the optimum grids system for the present problem has 101 grids (M=101) in the x direction, 51 grids (N=51) in the y direction for the heat sink.

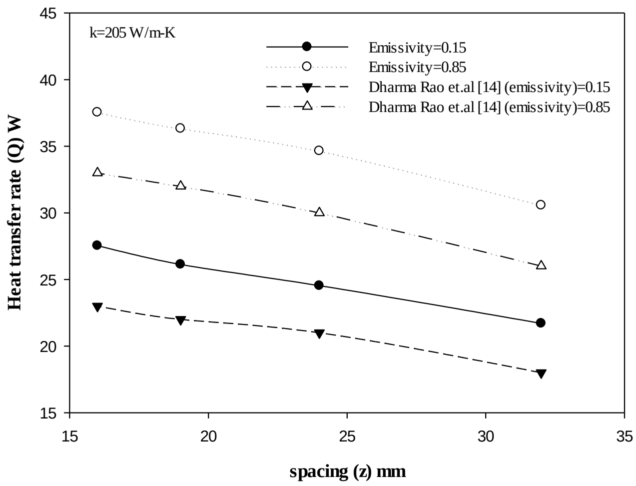


Fig. 2 Spacing Vs Heat transfer rate

The spacing of the heat sink is compared with the numerical analysis of Dharma Rao et al. [1] and it was observed that the increasing with fins the heat transfer rate increases and with increasing with emissivity temperatures of the heat sink decreases and heat transfer rate increases asymptotically. The radiation plays an important role in heat dissipation process with a rejection of 20%.

4.2 study of fin length optimization:

From fig-3 it was perceived that the maximum temperature is about 320K for the fin height of 30mm and it 314K for the fin height of 60mm. But the temperature profile is uniform throughout the fin at h=100W/m$^2$K for a forced convection regime where there is not much deviation for heights of 30mm and 60mm.Hence it shows that the increase in height of the fin does not affect more variation in temperatures, so for further studies the height of the fin is considered as 30mm.

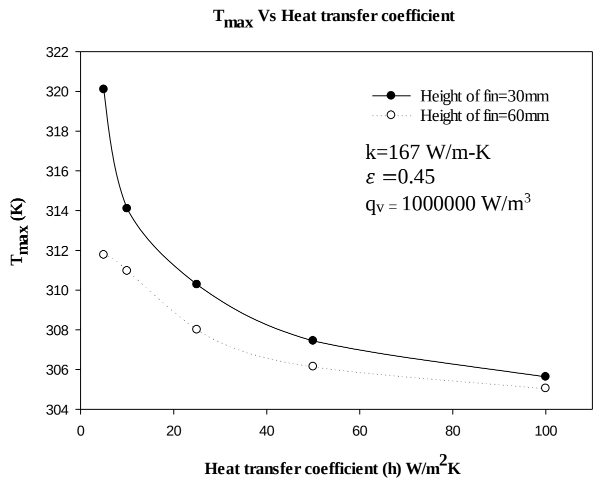


Fig. 3 Variation of temperature distribution for different heights of the fin

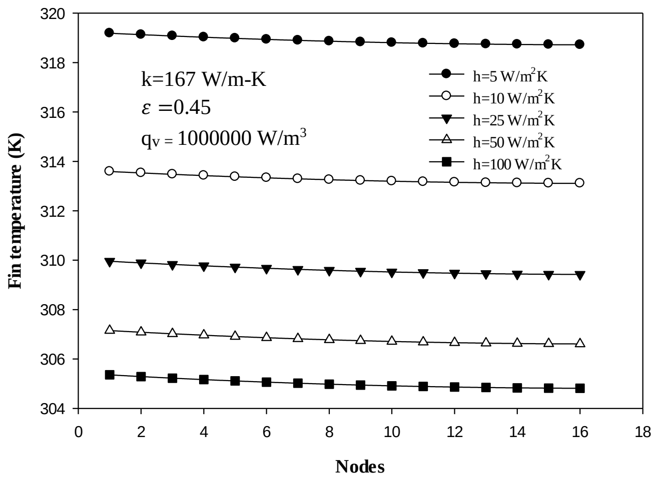


Fig. 4 Variation of temperature distribution along the fin in various regimes of convection

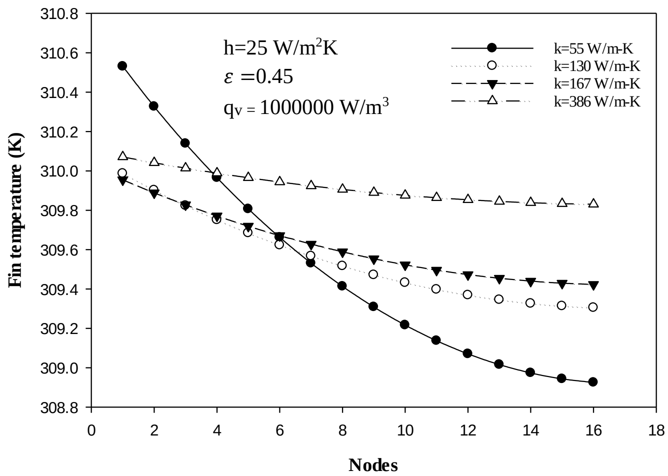


Fig. 5 Variation of temperature distribution along the fin for various materials of thermal conductivity

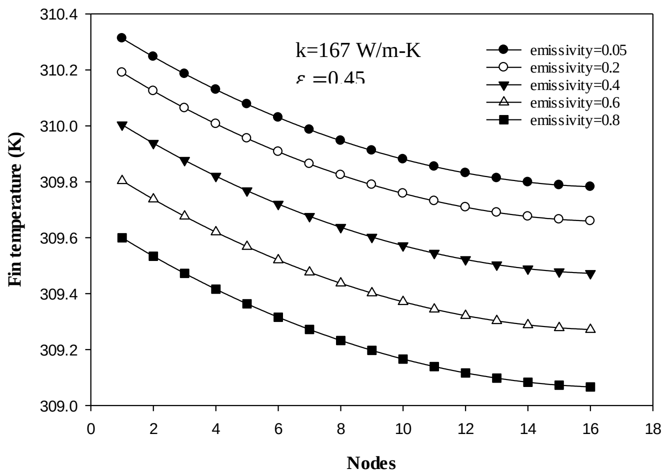


Fig. 6 Variation of temperature distribution along a fin with different values Emissivity

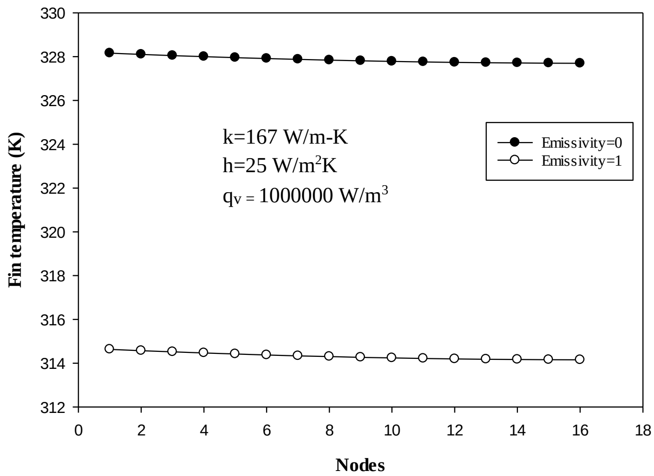


Fig. 7 Variation of temperature distribution along the fin with and without radiation

The above graph shows the fin temperature profile for the fixed values of k=167 W/m-K and h=5 W/m$^2$K for a free convection regime, by considering with and without radiation effect. From the above plotted graph, shows the maximum fin temperature obtained for surface emissivity=0, by that no radiation takes place from the heat sink and the heat does not omit from the surface. Since the heat dissipation will be slow due to the free convection regime. The second profile shows the temperatures gets low if the radiation effect is considered and the more heat is to be omitted from the surface, because emissivity=1 is a pure black body emitter that emits heat quicker and convection effect will be low due to free convection regime.

4.3 Study of local temperature profiles by varying thermal conductivity, heat transfer coefficient and emissivity

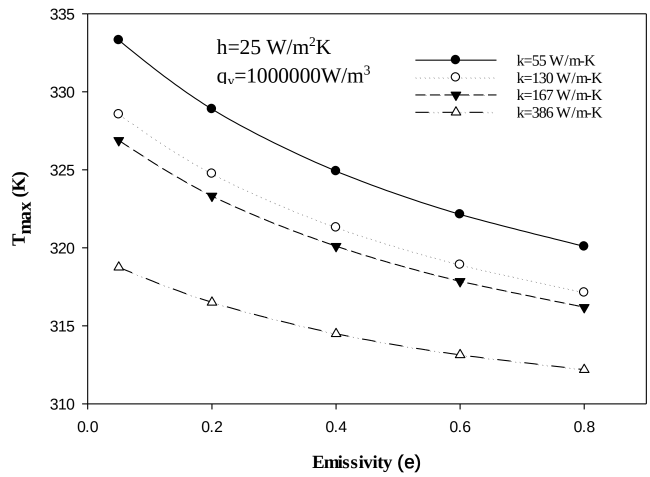


Fig. 8 Variation of local temperature scattering for h=5 W/m$^2$K and by varying Thermal Conductivity and Emissivity

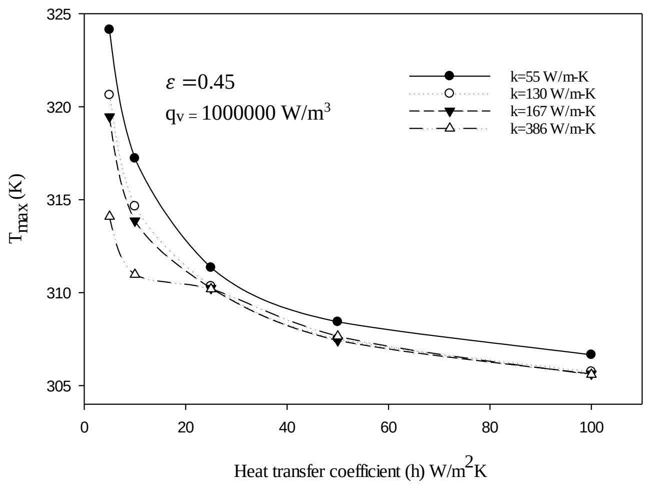


Fig. 9 Variation of local temperature distribution by increasing heat transfer coefficient with different materials of Thermal Conductivity

## 5. CONCLUSIONS

The heat sink performance had been studied for various regimes of conduction, convection and radiation, the numerical results shown that the performance of temperature distribution will be more effective while the radiation affect is considered and with the forced convection regime. The results are validated with different numerical studies and it was concluded that maximum temperature dissipation is more possible with high radiation effect (by increasing the value of emissivity). And one should not neglect the radiation affect while the studies performed further for heat sink analysis.

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