Optimization of Cooling Fan Speed for Heat Transfer Enhancement of Electronic Chip Using CFD

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Abstract. Demand of high-performance personal computers have highly increased today which in turn has increased the need for the efficient cooling system. In heat transfer through forced convection phenomenon, the former depends upon the variation in fluid velocity. The analysis of this paper results that variation in fluid velocity plays a key role in increasing the heat transfer rate and helps to meet the desired cooling environment for the safe performance of electronic components. The fan location is fixed above the chip and fluid velocity is varied and behavior of heat transfer rate is visualized for better design of the cooling system. Simulation has been carried out on ANSYS 15.0 (modeling on ICEM CFD & results from FLUENT). The k-ε turbulence model has been applied.

Keywords: Computational Fluid Dynamics (CFD), ANSYS, Forced Convection, Chip Cooling, Heat Transfer

1. Introduction

Global industries today are hugely demanding the innovations and developments in design processes and engineering methods. Prototyping of large and complex engineering equipment is costly as well as time taking. Thus, computational simulation techniques are gaining importance in research and development area. Computational fluid dynamics is an effective tool in analyzing the fluid forces their behavior and their effects on the victimized components. Fluid as a source of energy, its use in heating and cooling applications is in huge demand today. Advancement in technology has provided a better platform to use different types of fluid for effective cooling [1-9].

Technology today is seeking compactness which promotes the use of small ICs and chips. These small electronic components though are fast but emit huge bumps of heat, which if not cast off the device can cause a lot of harm to the parent device. Thus the advancement and development of cooling systems have become a need of the hour. Cooling system requirements are not only limited to the electronic components. All the machine components generate heat and require cooling systems. In personal computers, the cooling is carried out using fans or other systems like a heat pipe. The proper visualization and analysis of these systems are very necessary as otherwise may make the parent device bulky or if could not fulfill cooling requirements may destroy the device.

Some researchers have done their work on-chip cooling and cooling through the extended surfaces. Saroj Kumar Patra analyzed the flow through a channel via an obstruction for laminar, transient flow and plotted different contours for pressure, temperature, velocity and Nusselt number [10]. Arularasan R. and Velraj R. found the optimal design of the heat sink carried out on a parallel plate heat sink considering the geometric parameters [11]. R. Boukhanouf and A. Haddad simulated an electronics
enclosure cooling system to be used as part of a larger radar control system using CFD [12]. N. Hariharan, A.S. Manirathnam, S. Vellingiri, and R.S. Mohankumar founded the better cooling solution for notebook computers using miniature loop heat pipe with the help of CFD [13]. M.A.I. Rashid, M.F Ismail, and M. Mahbub found that circular pin fin carbon nano-tube based micro-channel heat sink shows better thermal performance than the rectangular pin fins [14]. Randeep Singh, Aliakbar Akbarzadeh, and Masataka Mochizuki calculated the various design parameters for the design of future laptops based on the miniature loop heat pipe (mLHP) [15]. Gupta S. K. et al. analyze heat transfer enhancement of electronic chip using computational fluid dynamics technique. He concluded that the heat transfer rate increases drastically by changing the location of cooling fan [16-20].

2. Governing Equations

The governing equations considered for the analysis of the convective heat transfer coefficient through the flow over cylinder are as follows:

2.1. Continuity Equation

\[
\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u)}{\partial x} + \frac{\partial (\rho v)}{\partial y} = 0
\]  

(1)

2.2. Momentum Equation

\[
\frac{Du}{Dt} = X - \frac{1}{\rho} \frac{\partial p}{\partial x} + \frac{\mu}{\rho} \left[ \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right] 
\]

\[
\frac{Dv}{Dt} = Y - \frac{1}{\rho} \frac{\partial p}{\partial y} + \frac{\mu}{\rho} \left[ \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right]
\]  

(2)

(3)

2.3. Energy Equation

\[
\rho c_p \left( u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} \right) = k \left( \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right)
\]  

(4)

2.4. \( k - \varepsilon \) Equation

\[
\frac{\partial k}{\partial t} + \text{div}(\rho u k) = \text{div} \left[ \left( \mu_t + \frac{\rho \mu_t}{\varepsilon} \right) \text{grad} \right] + \rho \mu_t S - \rho \varepsilon
\]  

(5)

\[
\frac{\partial \varepsilon}{\partial t} + \text{div}(\rho u \varepsilon) = \text{div} \left[ \left( \mu_t + \frac{\rho \mu_t}{\varepsilon} \right) \text{grad} \right] + C_{\mu_t} \rho \mu_t \left( \frac{\varepsilon}{\mu_t} \right) - C_{\mu_t} \rho \mu_t \varepsilon^2
\]  

(6)

3. Computational Methodology

3.1. Geometrical Modelling

The computational methodology has been employed to analyze the rate of heat transfer achieved through the cooling fan with a change in its velocity. The two integrated chips system is allowed to cool using the fan installed at the top wall which is considered to be the inlet. The computational domain, considering which the analysis has been carried out is shown in figure 1.
3.2. Meshing

For the accurate and exact analysis of the computational domain, it is divided into many a number of small finite elements. This so generated is called as a mesh. The analysis work carried out on the small elements is integrated to the results of whole geometry. Geometry and mesh are generated on the ICEM CFD 15.0. Thus mesh generation helps in finding out the précised results. Exponential1, Exponential2, Bi-geometric, uniform etc. are the mesh laws used to for mesh generation. The mesh information is given in table 1.

Table – 1 Mesh Information

| Mesh Information                  | Value                     |
|----------------------------------|---------------------------|
| Quadrilateral Cells              | 122588, Zone 12           |
| Interior Faces                   | 244195, Zone 13           |
| Velocity-inlet Faces             | 218, Zone 14              |
| Pressure-outlet Faces            | 218, Zone 15              |
| Wall Faces                       | 237, Zone 16              |
| Wall Faces                       | 237, Zone 17              |
| Wall Faces                       | 358, Zone 18              |
| Wall Faces                       | 267, Zone 19              |
| Nodes                            | 123570                    |
| Min. Orthogonal Quality         | 1.00000e+00               |
| Maximum Aspect Ratio             | 1.70209e+02               |

3.3. Boundary Condition

![Figure 1 Computational Domain](image1.png)

![Figure 2 Quadrilateral Mesh Grid](image2.png)
The boundary conditions are given in certain regions in a domain where the flow is needed to be analyzed. Cooling of chips is achieved using the ambient air. Boundary conditions information is given in table 2. Setup is initialized and run to reach the convergence rate required.

Table – 2 Boundary Conditions for the domain

| Zone    | Boundary Condition                                |
|---------|--------------------------------------------------|
| Inlet   | Velocity-inlet                                   |
| Outlet  | Pressure-outlet                                  |
| Wall    | No-slip condition with adiabatic wall            |
| Chip 1  | Heat Flux                                        |
| Chip 2  | Heat Flux                                        |

3.4. Solution and Discussion

An implicit algebraic multigrid method of the solution along with second-order upwind scheme is used in the discretization to converge the results with higher accuracy. Pressure-velocity correlation is used to establish velocity-pressure coupling using Semi-Implicit Method for Pressure-Linked Equations (SIMPLE) algorithm. Continuous residual monitoring is done to keep a check on all parameters for proper convergence rate.

4. Results

The heat transfer variations on the chips for various air flow velocities have been plotted and shown in fig 3. Contours of pressure and velocity are generated using the software package to determine the flow behaviour and its thermal effects on chips are shown in table 4 and table 5. The calculated values are shown in the table-3

![Figure 3](image-url)  
**Figure 3** Variation of Surface Heat Transfer Coefficient for Chip 1 and Chip 2 at different air velocities

Table – 3 Results obtained for different velocities

| Velocity | Parameter          |
|----------|--------------------|
|          | Heat Transfer Coefficient, h (W/m²-K) | Minimum Temperature (K) | Maximum Temperature (K) |
|          | 120                | 5                   | 10                   |
|          | 140                | 7                   | 15                   |
### Table – 4 Velocity and temperature contours

| Velocity (m/sec) | Chip 1 | Chip 2 | Chip 1 | Chip 2 | Chip 1 | Chip 2 |
|------------------|--------|--------|--------|--------|--------|--------|
| 2                | 69.529| 69.283 | 231.495| 3173.00| 5185.52| 5185.522|
| 3                | 69.572| 69.283 | 2023.006| 288.511| 5185.524| 5185.524|
| 5                | 69.620| 72.439 | 1735.502| 259.007| 5185.524| 5185.524|
| 6                | 71.662| 70.989 | 1448.002| 231.507| 5185.524| 5185.524|
| 8                | 76.159| 79.100 | 1160.502| 116.502| 5185.524| 5185.524|
| 9                | 81.072| 85.528 | 873.0009| 873.000| 5185.524| 5185.429|

![Contour of Velocity Magnitude](#)

![Contour of Velocity Magnitude](#)

![Contour of Velocity Magnitude](#)
Table – 5 Temperature contours

| Velocity (m/sec) | Temperature Contour |
|-----------------|---------------------|
| 2               | ![Temperature Contour 2](image) |
| 5               | ![Temperature Contour 5](image) |
| 8               | ![Temperature Contour 8](image) |
5. Conclusion

The following conclusions can be made from this analysis:
The increase in cooling rate is achieved with increasing velocity of fluid.
The heat transfer coefficient for chip 1 and chip 2 are increased by 16.6 % & 23.44 % respectively for velocity variation of 2 m/s to 10 m/s.

Nomenclature

\( \rho \): Density of fluid flowing
\( u \): Velocity of flow in \( x \)-direction
\( v \): Velocity of flow in \( y \)-direction
\( p \): Pressure in the flow direction
\( X \): \( x \)-direction Body force
\( Y \): \( y \)-direction Body force
\( T \): Fluid temperature
\( T_\infty \): Ambient air temperature
\( k \): Thermal Conductivity of the fluid
\( Re \): Reynolds Number
\( h \): Heat transfer coefficient
\( \mu \): Dynamic Viscosity
\( \mu_t \): Eddy viscosity
\( \nu \): Kinematic Viscosity
\( k \): Turbulent kinetic energy
\( \varepsilon \): Turbulent dissipation rate
\( G \): Turbulent generation rate
\( \sigma_k \): Constant
\( \sigma_\varepsilon \): Constant
\( C_1 \varepsilon \): Constant
\( C_2 \varepsilon \): Constant

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