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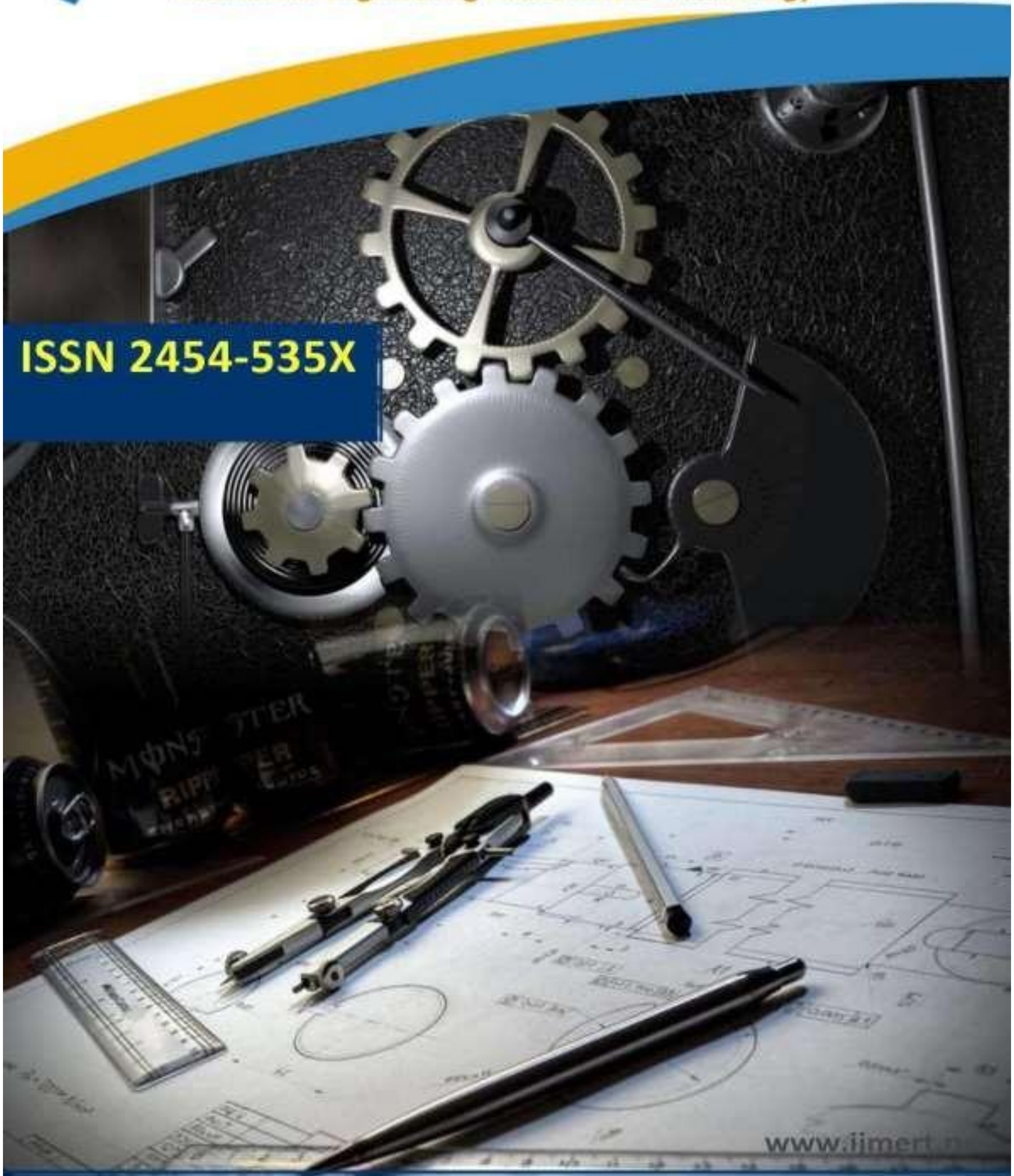

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APPLICATION-BASED THERMAL ANALYSIS OF AN ELECTRONIC SYSTEM USING NATURAL CONVECTION AND RADIATION

[1]Mrs. B. Siva Naga Ramya ,
[2] N.Jnaneswari, [3]R.Jai Satya Shankar, [4]M.Sivannarayana, [5]D.Satya Sudheer

[1]Assistant Professor,Department of Mechanical Engineering
Pragati Engineering College (Autonomous)
(Affiliated to JNTUK)
Kakinada District, Surampalem -533437

[2,3,4,5] Students, Department of Mechanical Engineering
Pragati Engineering College (Autonomous)
(Affiliated to JNTUK)
Kakinada District, Surampalem -533437
[1]Mail.Id: ramya.b@pragati.ac.in [2]Mail.Id:lnaneswarinallamilli67@gmail.com

[3]Mail.Id:relangijaisatyashankar@gmail.com [4]Mail.Id:medidisivannarayana@gmail.com
[5]Mail.Id: sudheernaidu189@gmail.com

ABSTRACT

Miniaturization of electronic devices has led to increased heat generation per unit volume, creating serious thermal management challenges. Efficient removal of heat from electronic chips is critical to ensure reliability, performance, and longevity.

In this study, Computational Fluid Dynamics (CFD) simulations are performed to analyze the thermal behavior of a single electronic chip module. The chip is modeled using ANSYS SpaceClaim and analyzed in ANSYS Fluent by solving governing equations for laminar viscous flow through a channel with obstruction.

Keywords: CFD, Natural Convection, Radiation, SpaceClaim, Fluent, Heat Sink

CHAPTER 1

INTRODUCTION

1.1 Background

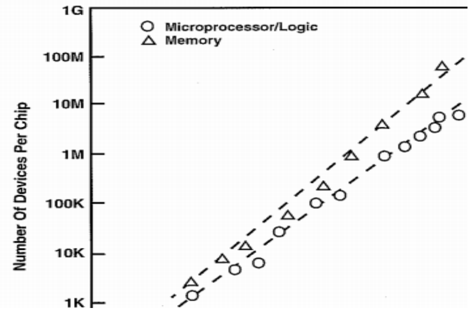
Electronic systems are integrated into nearly every aspect of modern life — from mobile phones and laptops to aerospace systems and defense equipment.

As device size decreases:

- Power density increases
- Heat flux increases
- Reliability risk increases

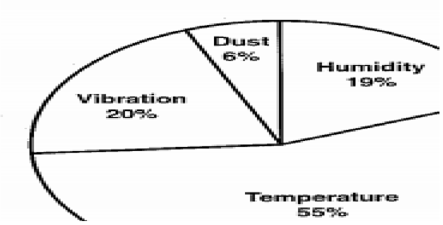
Historically, early computers such as ENIAC required massive cooling systems to remove 140 kW of heat. Although transistor and integrated circuit technologies reduced size, packaging density dramatically increased heat generation per unit area.

Modern microprocessors contain billions of transistors, producing significant localized heat flux.



1.1 Number of devices per chip

It has been found that for every 2° C temperature rise, the reliability of a silicon chip will be decreasedby about 10 %. The major cause of an electronic chip failure is temperature rise (55%) as against other factors which account for 20 % vibration, 19 % humidity, and 6 % dust. So, it’s a great challenge for the packaging engineers to remove the heat from the electronics chips very effectively.



1.1 Heat in the electronic chips

1.2 Importance of Thermal Management

Studies show:

- For every 2°C rise in temperature, silicon chip reliability decreases by 10%.
- 55% of electronic failures are caused by temperature rise.
- Other factors include vibration (20%), humidity (19%), and dust (6%).

Thus, efficient thermal management is essential.

1.3 Cooling Techniques in Electronics

1.3.1 Air Cooling

- Forced convection
- Serial or parallel airflow
- Low cost
- Most widely used

1.3.2 Hybrid Air–Water Cooling

- Air cooling + water heat exchangers
- Reduces air temperature rise

1.3.3 Liquid Cooling

- Cold plates
- Coolant distribution unit (CDU)
- Higher heat removal capacity

1.3.4 Immersion Cooling

- Direct liquid contact
- Eliminates thermal interface resistance
- Suitable for high heat flux

CHAPTER 2

HEAT TRANSFER THEORY

2.1 Convection

Convection is heat transfer due to bulk motion of fluid.

Two types:

Natural Convection

Occurs due to buoyancy forces caused by density differences.

Forced Convection

Occurs due to external devices such as fans or pumps.

Heat transfer by convection is governed by:

$Q = hA(T_s - T_\infty)$

Where:
h = heat transfer coefficient
A = area
T_s = surface temperature
T_∞ = ambient temperature

2.2 Radiation

Radiation is heat transfer through electromagnetic waves.

Governed by:

$Q = \sigma\varepsilon A(T^4 - T_\infty^4)$

Where:
σ = Stefan-Boltzmann constant
ε = emissivity

In electronic cooling, radiation contributes alongside convection.

CHAPTER 3

COMPUTATIONAL FLUID DYNAMICS (CFD)

CFD solves fluid flow equations numerically.

3.1 Governing Equations

For laminar flow:

- Continuity equation
- Navier–Stokes equations
- Energy equation

3.2 CFD Process

1. Pre-processing
    - Geometry creation
    - Mesh generation
    - Material properties
    - Boundary conditions
2. Solver
    - Pressure-velocity coupling
    - Iterative solution
3. Post-processing
    - Temperature contours

  - Velocity vectors
  - Residual plots

3.3 Pressure–Velocity Correction

The solution process:

1. Guess pressure field
2. Solve momentum equations
3. Apply pressure correction
4. Update velocities
5. Repeat until convergence

CHAPTER 4

MATERIAL PROPERTIES

Three materials were analyzed as heat sinks:

4.1 Copper (Cu)

- Thermal conductivity ≈ 387.6 W/m·K
- Excellent conductor
- High cost
- High reliability

4.2 Silver (Ag)

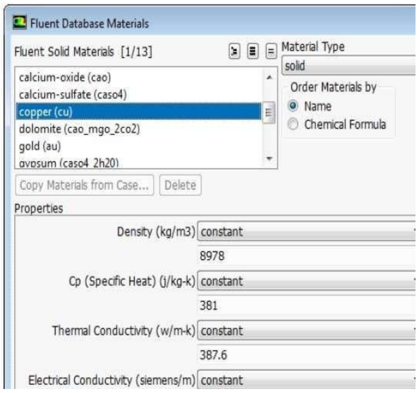
- Thermal conductivity ≈ 419 W/m·K
- Highest among metals
- Expensive

4.3 Aluminium (Al)

- Thermal conductivity ≈ 241 W/m·K
- Lightweight
- Economical
- Widely used

COPPER

A Chemical element, a reddish, extremely ductile metal of Group 11 (Ib) of the periodic table that is an unusually good conductor of electricity and heat. Copper is found in the free metallic state in nature. This native copper was first used (c. 8000 BCE) as a substitute for stone by Neolithic (New Stone Age) humans. Metallurgy as copper was cast to shape in molds (c. 4000 BCE), was reduced to metal from ores with fire and charcoal and was intentionally alloyed with tin as bronze (c. 3500BCE). The Roman supply of copper came almost entirely from Cyprus. It was known as *aes Cyprium*, “metal of Cyprus,” shortened to *cuprum* and later corrupted to *cuprum*.



Fluent Solid Materials [1/13]
calcium-oxide (cao)
calcium-sulfate (caso4)
copper (cu)
dolomite (cao_mgo_2co2)
gold (au)
gypsum (caso4_2h20)

Material Type: solid

Order Materials by
● Name
○ Chemical Formula

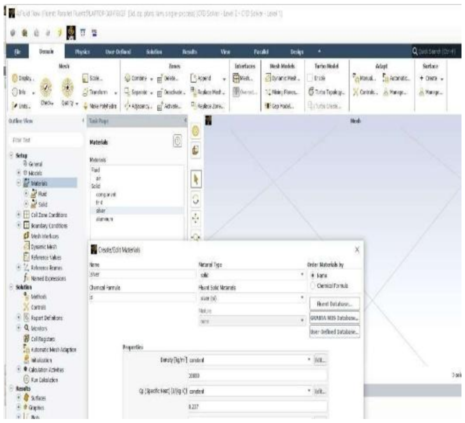
Properties
Density (kg/m3): constant
8978
Cp (Specific Heat) (j/kg-k): constant
381
Thermal Conductivity (w/m-k): constant
387.6
Electrical Conductivity (siemens/m): constant

properties of copper

SILVER

Silver is a chemical element with the symbol Ag and atomic number 47. A soft, white, lustrous transition metal, it exhibits the highest electrical conductivity, thermal conductivity, and reflectivity of any metal. The metal is found in the Earth's crust in the pure, free elemental form ("native silver"), as an alloy with gold and other metals, and in minerals such as argentite and chlorargyrite. Most silver is produced as a by-product of copper, gold, lead, and

zinc refining.



Name: silver
Material Type: solid
Fluent Solid Materials: silver (ag)
Properties
Density [kg/m³]: constant
Cp (Specific Heat) [J/(kg K)]: constant

properties of silver

ALUMINIUM

Aluminium (aluminium in American and Canadian English) is a chemical element with the symbolAl and the atomic number 13. Aluminium has a density lower than those of other common metals, at approximately one third that of steel. It has a great affinity toward oxygen and forms a protectivelayer of oxide on the surface when exposed to air. Aluminium visually resembles silver, both in its colour and in its great ability to reflect light. It is soft, non-magnetic and ductile. It has one stable isotope, 27Al; this isotope is very common, making aluminium the twelfth most common element in the Universe. The radioactivity of 26Al is used in radiodating.

CHAPTER 5

PROBLEM DEFINITION

Objective

To analyze temperature variation in a single electronic chip using:

- Natural convection
- Radiation
- CFD simulation

And compare cooling performance of:

- Copper
- Aluminium
- Silver

METHODOLOGY

CONVECTION

Convection is the process of heat transfer by the bulk movement of molecules within fluids such as gases and liquids. The initial heat transfer between the object and the fluid takes place through conduction, but the bulk heat transfer happens due to the motion of the fluid.

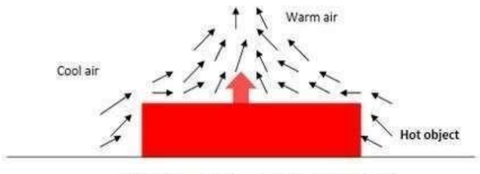
There are two types of convection, and they are:

NATURAL CONVECTION

When convection takes place due to buoyant force as there is a difference in densities caused by the difference in temperatures it is known as natural convection.

Examples of natural convection are oceanic winds.

[redacted]



Natural convection heat transfer from a hot body.

[redacted]

Fig 3.1 Natural Convection

FORCED CONVECTION

When external sources such as fans and pumps are used for creating induced convection, it is known as forced convection.

Examples of forced convection are using water heaters or geysers for instant heating of water and using a fan on a hot summer day. Forced convection is related to ***Newton's law of cooling.***

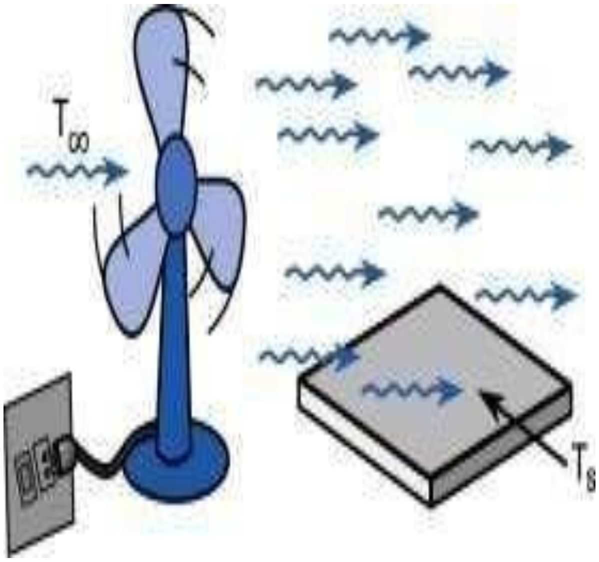
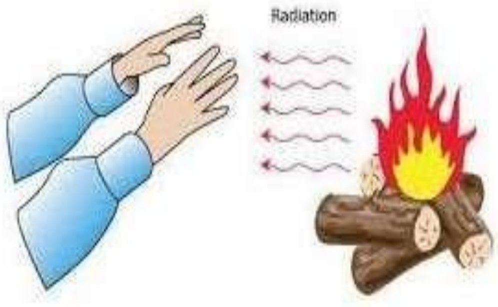


Fig 3.2 forced Convection

RADIATION

The word "radiation" arises from the phenomenon of waves *radiating* (i.e., traveling outward in all directions) from a source. This aspect leads to a system of measurements and physical units that are applicable to all types of radiation.

Fig 3.3 Radiation



COMPUTATIONAL FLUID DYNAMICS:

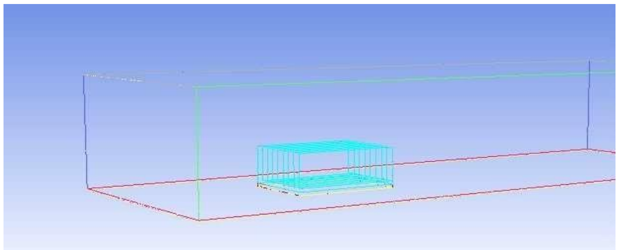
Computational fluid dynamics (CFD) is a branch of fluid mechanics that uses numerical analysisand data structures to analyze and solve problems that involve fluid flows. Computers are used to perform the calculations required to simulate the free-stream flow of the fluid, and the interaction of the fluid (liquids and gases) with surfaces defined by boundary conditions. With high-speed supercomputers, better solutions can be achieved, and are often required to solve the largest and most complex problems. Ongoing research yields software that improves the accuracy and speed of complex simulation scenarios such as transonic or turbulent flows.

CHAPTER 6

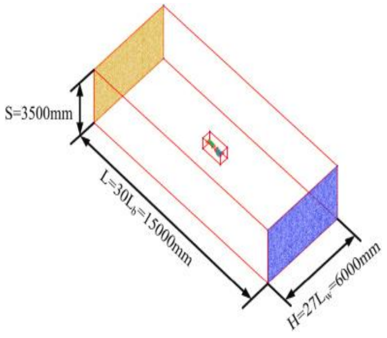
MODELING AND METHODOLOGY

MODELING OF CHIP

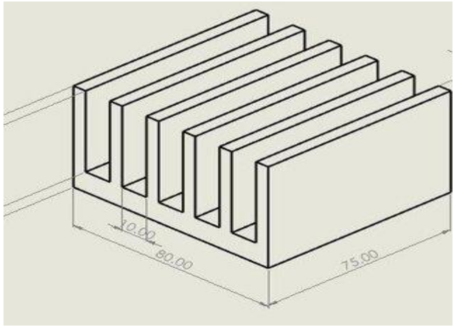
The general model is shown below. It consists of a heat source i.e., a chip. The heat Shink is made up of different materials like copper, silver, and aluminium. By using the analysis we model the geometry.



4.1 Modeling of chip



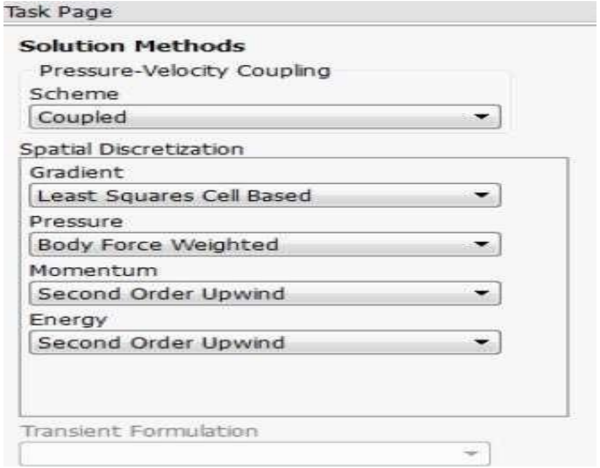
ANALYSIS



Pressure-Velocity Correction

The pressure correction technique is basically an iterative approach, where some innovative physical reasoning is used to construct the next iteration from the results of the previousiteration.

4.2 pressure velocity correction



Solution Methods

Pressure-Velocity Coupling

Scheme: Coupled

Spatial Discretization

Gradient: Least Squares Cell Based

Pressure: Body Force Weighted

Momentum: Second Order Upwind

Energy: Second Order Upwind

Transient Formulation

6.1 Geometry Creation

- Single chip model
- Heat source at base
- Heat sink attached
- Flow channel modeled

Created using ANSYS SpaceClaim.

6.2 Boundary Conditions

INLET:

- Temperature = 45°C

OUTLET:

- Gauge pressure = 0 Pa

Initialization:

- Velocities = 0
- Gauge pressure = 0

Zone Name: inlet

Total Temperature (c) 45 constant

Fig 4.3 Pressure Inlet

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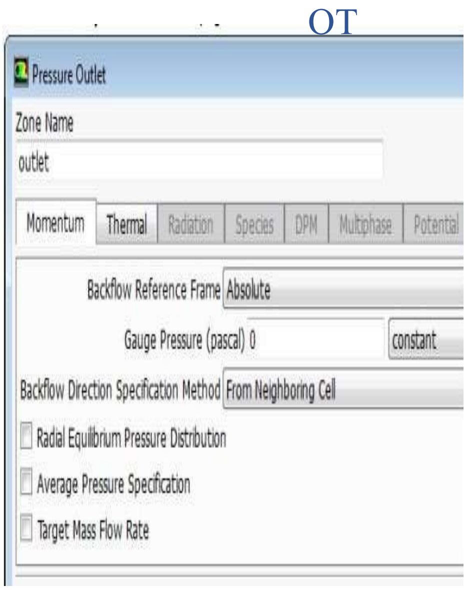


Pressure Outlet

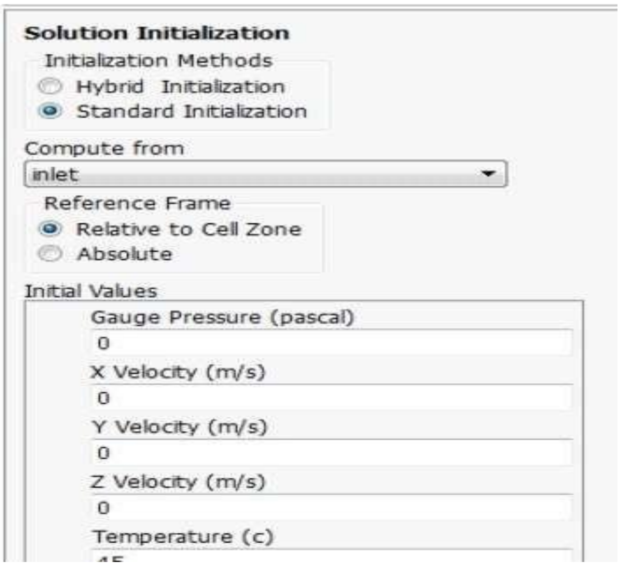
Zone Name
outlet

Backflow Reference Frame Absolute
Gauge Pressure (pascal) 0 constant
Backflow Direction Specification Method From Neighboring Cell
☐ Radial Equilibrium Pressure Distribution
☐ Average Pressure Specification
☐ Target Mass Flow Rate

Fig 4.4 Pressure Outlet

INITIALIZATION

In this process gauge pressure, X velocity , Y velocity and Z velocity taken as zero.


Solution Initialization

Initialization Methods
○ Hybrid Initialization
● Standard Initialization

Compute from
inlet

Reference Frame
● Relative to Cell Zone
○ Absolute

Initial Values
Gauge Pressure (pascal)
0
X Velocity (m/s)
0
Y Velocity (m/s)
0
Z Velocity (m/s)
0
Temperature (c)

6.3 Mesh

- Structured mesh
- Fine near chip surface
- Coarser away from heat source

CHAPTER 7

RESULTS AND DISCUSSION

7.1 CFD Analysis – Copper

- Thermal conductivity = 387.6 W/m·K
- Chip temperature ≈ 364.5 K
- Moderate energy variation

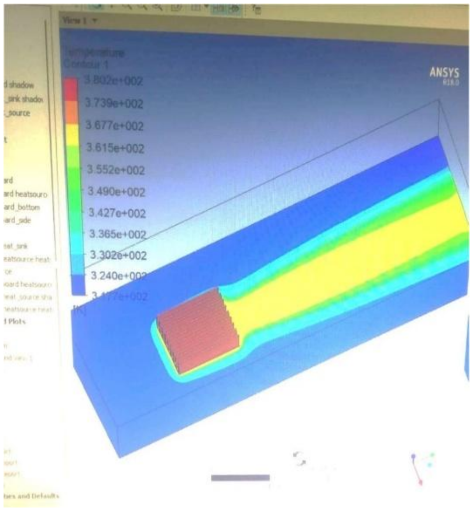


Fig.5.1 CFD Analysis for COPPER

7.2 CFD Analysis – Aluminium

- Thermal conductivity = 241 W/m·K
- Chip temperature ≈ 360 K
- Good performance
- Lower cost

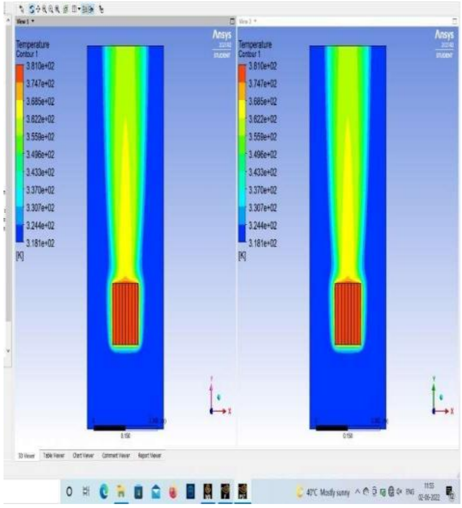


Fig 5.2 CFD Analysis for ALUMINIUM

7.3 CFD Analysis – Silver

- Thermal conductivity = 419 W/m·K
- Chip temperature ≈ 369.5 K
- Highest energy variation

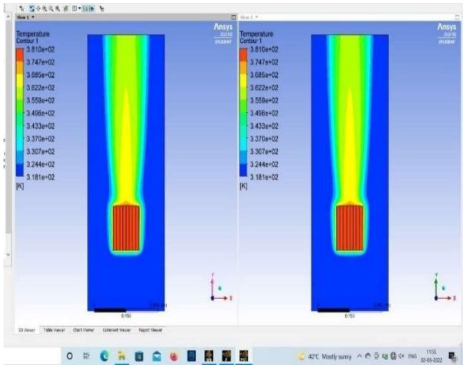


Fig 5.3 CFD Analysis for SILVER

TABLE 5.1 REMOVAL OF TEMPERATURE FROM CHIP

S.NO	MATERIALS	TEMPERATURE
01	ALUMINIUM	**360 k**
02	COPPER	**364.5 k**
03	SILVER	**369.5 k**

Scaled Residuals

SILVER

If scaled residuals contains continuity, x-velocity, y-velocity, z-velocity and energy. In this analysis, we will find the energy variation gradually decreasing due to the high thermal conductivity of silver

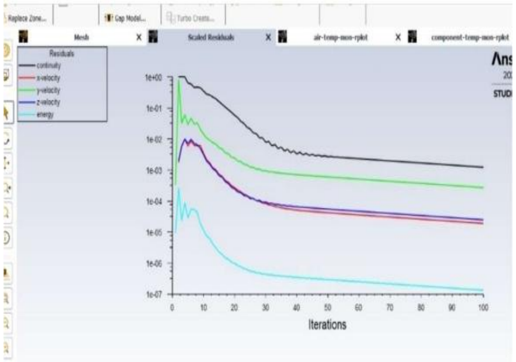


Fig 5.4 Scaled residuals for silver

7.4 Temperature Comparison Table

S.No	Material	Temperature (K)
1	Aluminium	360
2	Copper	364.5
3	Silver	369.5

7.5 Scaled Residual Analysis

Residuals include:

- Continuity
- X-velocity
- Y-velocity
- Z-velocity
- Energy

Silver:

- Fast energy convergence
- High thermal transfer

Copper:

- Moderate residual decay

Aluminium:

- Slower convergence
- Lower conductivity

CHAPTER 8

DISCUSSION

Observations:

- Higher thermal conductivity → Higher heat transfer
- Silver provides best thermal performance
- Copper provides balanced performance
- Aluminium provides best cost-performance ratio

Interestingly, scaled residual behavior shows copper gives stable convergence.

CHAPTER 9

COMPARISON AND EVALUATION

Property	Silver	Copper	Aluminium
Thermal Conductivity	Highest	High	Moderate
Cost	Very High	High	Low
Weight	Medium	High	Low
Cooling Efficiency	Best	Very Good	Good

Final engineering choice depends on:

- Budget
- Application
- Weight constraints
- Required cooling rate

CHAPTER 10

CONCLUSIONS

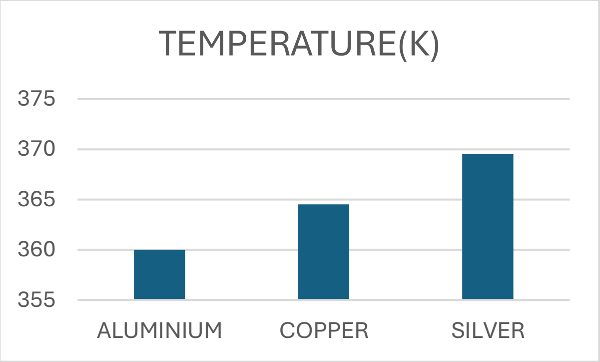
- CFD modeling successfully simulated chip cooling.
- Natural convection and radiation were analyzed.
- Silver provides highest heat transfer capability.
- Aluminium is most economical.
- Copper provides optimal combined performance.

For practical industrial applications:

- Aluminium is preferred for cost-sensitive systems.
- Copper is preferred for balanced performance.
- Silver is suitable for high-performance systems where cost is not a concern.

CONCLUSIONS

- Modeling of chip used in electronics devices is done using space claim modeler. Analysis of chip is completed using radiation and convection modes of heat transfer.The temperature variation in chip utilizing copper, aluminium and silver is obtained.



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