**NUMERICAL INVESTIGATION ON CONVECTIVE HEAT TRANSFER ENHANCEMENT USING VARIOUS NANO FLUIDS AND DIFFERENT DUCT GEOMETRIES**

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**NUMERICAL INVESTIGATION ON CONVECTIVE HEAT TRANSFER ENHANCEMENT USING VARIOUS NANO FLUIDS AND DIFFERENT DUCT GEOMETRIES**

***Thesis submitted to***

***National Institute of Technology Andhra Pradesh***

***for the award of the degree***

***of***

***Bachelor of Technology***

***by***

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**APPROVAL SHEET**

This thesis/dissertation/report entitled *NUMERICAL INVESTIGATION ON CONVECTIVE HEAT TRANSFER ENHANCEMENT USING VARIOUS NANO FLUIDS AND DIFFERENT DUCT GEOMETRIES*by Sai Praneeth Jangam, KadiyamSrikar, D.Sai Ganesh,VaddiYuvarajis approved for thedegree of“Bachelor of Technology”.

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**Chairman**

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Place :

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**CERTIFICATE**

It is certified that the work contained in the thesis titled “TOPOLOGY OPTIMIZATION OF HEAT SINK” by “Sai Praneeth Jangam, bearing Roll No: 711956”,“KadiyamSrikar, bearing Roll No: 711928”,“D Sai Ganesh, bearing Roll No: 711919”,“VaddiYuvaraj, bearing Roll No: 711961”has been carried out under my/our supervision and that this work has not been submitted elsewhere for a degree\*

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**ABSTRACT**

This project report explores the potential of using nanofluids to enhance the performance of a solar water heater. The study investigates the convective heat transfer performance of three types of nanofluids, SiO2, TiO2, and Al2O3, at different volume concentrations and Richardson numbers. Computational fluid dynamics software ANSYS Fluent 18.1 is used to simulate the heat transfer performance in an equilateral triangular cross sectioned duct and six other geometries. A mesh sensitivity test is conducted to optimize the mesh size for the simulation

The results indicate that Al2O3 nanofluid exhibits the highest heat transfer enhancement among the three types of nanofluids. Furthermore, the optimal concentration of nanoparticles for the highest heat transfer performance varies with the geometry of the duct and the Richardson number. These findings have significant implications for the design and optimization of solar water heaters using nanofluids and could contribute to the development of more efficient and sustainable solar energy systems.

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**Chapter 1**

**Introduction**

Fossil fuels such as coal, oil, and gas have been the primary source of energy for many years. However, the burning of fossil fuels has negative impacts on the environment and contributes to climate change. Therefore, it is important to reduce our reliance on fossil fuels and transition towards cleaner, renewable sources of energy.

One way to do this is to replace the use of fossil fuels for heating with solar heaters. Solar heaters use energy from the sun to heat water, which can then be used for various purposes, including space heating and domestic hot water.

The advantages of using solar heaters instead of fossil fuels include:

Reduced greenhouse gas emissions: Solar heaters produce zero emissions, whereas the burning of fossil fuels releases carbon dioxide and other harmful gases into the atmosphere.

Reduced dependence on non-renewable resources: Fossil fuels are finite resources, and their availability is decreasing. Solar heaters, on the other hand, rely on an abundant and renewable energy source – the sun.

Cost savings: Although the initial cost of installing a solar heating system may be higher than that of a fossil fuel-based system, the ongoing operational costs of a solar system are much lower, as there are no fuel costs.

Increased energy security: By using a renewable energy source such as the sun, we can reduce our reliance on fossil fuels and increase our energy security.

In summary, the use of fossil fuels has negative impacts on the environment and contributes to climate change. By replacing them with solar heaters, we can reduce greenhouse gas emissions, reduce our dependence on non-renewable resources, save costs, and increase energy security.

**1.2 How does Solar Water heater Works?**

A solar water heater is a device that uses energy from the sun to heat water. The basic working principle of a solar water heater involves the conversion of solar energy into heat energy, which is then used to heat the water.

The most common type of solar water heater is the flat-plate collector system. This system consists of a flat-plate collector, a storage tank, and a circulation pump. The flat-plate collector is typically made of metal or plastic and is coated with a dark, heat-absorbing material. The collector is placed on the roof of a building or in an area that receives direct sunlight.

The collector absorbs solar radiation and converts it into heat, which is then transferred to a fluid circulating through the collector. In traditional solar water heaters, this fluid is typically water or a water-glycol mixture. The heated fluid is then pumped through a heat exchanger that transfers the heat to the water in the storage tank. The heated water is then available for use.

**1.3 Why nano fluids in solar water heaters are required?**

In recent years, researchers have been exploring the use of nanofluids in solar water heaters to improve their efficiency. Nanofluids are liquids that contain small particles, typically between 1 and 100 nanometers in size. These particles can be made of metals, ceramics, or other materials and have unique properties that can improve heat transfer.

When nanofluids are used in a solar water heater, the particles in the fluid can absorb more heat from the sun than the fluid alone. This results in a higher temperature of the fluid and a more efficient transfer of heat to the water in the storage tank. Additionally, the use of nanofluids can reduce the size of the collector needed to heat the same amount of water, making the system more compact and easier to install.

In summary, a solar water heater uses energy from the sun to heat water. The basic working principle involves the conversion of solar energy into heat energy, which is then transferred to a fluid circulating through a collector and then to the water in a storage tank. The use of nanofluids in solar water heaters can improve their efficiency by allowing for more heat to be absorbed and transferred to the water.

**Chapter 2**

**Literature Review**

The use of nanofluids for convective heat transfer enhancement has been a subject of extensive research in recent years. A literature review reveals that nanofluids have the potential to significantly enhance heat transfer in various heat transfer applications.

1. Circular tube with CuO/water nanofluid: Both theoretical and experimental results indicate that heat-transfer coefficients increase with nanoparticle concentration as well as the Peclet number. (Ferrouillat et al., 2011)
2. Equilateral triangular duct with Au and SiO2/water nanofluids: SiO2 nanofluid has the highest Nusselt number while Au nanofluid has the lowest Nusselt number. The apex angle of the triangular duct has remarkable influence on the Nusselt number. (Mohammed et al., 2011)
3. Isosceles triangular cross-section with water: Predicted the simultaneous existence of macroscopically large stable regions of laminar and turbulent flow during the transition phenomenon. (Hanks and Cope, 1970)
4. Equilateral and right isosceles triangles with CuO/water nanofluid: Application of solving an integro-differential eigenvalue problem arising in the discussion of laminar flow development in ducts. (Aggarwala and Gangal, 1975)
5. Vertical triangular cross-section with air: Axial (perimeter averaged) heat transfer coefficients along the side of each duct are obtained for laminar and transition to turbulent regimes of natural convection heat transfer. (Ali and Al-Ansary, 2009)
6. Circular tube with Transformer oil + Cu nanoparticles suspension and water + Cu nanoparticles: Hot-wire method used to measure the thermal conductivity of nanofluids, with the main objective of comparing data obtained by different organizations for the same samples. (Xuan and Li, 2000)
7. Vertical triangular cross-section with Al2O3/water nanofluid: Correlations for effective thermal conductivity and viscosity are synthesized and developed based on the reported experimental data. (Khanafer and Vafai, 2011)
8. Circular tube with Al2O3/water nanofluid: Presented an experimental investigation of the specific heat of the water-based Al2O3 nanofluid with DSC measurement. (Zhou and Ni, 2008)
9. Circular tube with CuO/water nanofluid: Both theoretical and experimental results indicate that heat-transfer coefficients increase with nanoparticle concentration as well as the Peclet number. (Heris et al., 2006 and Edalati et al., 2012)
10. Equilateral triangular duct with Al2O3/water nanofluid: There is an increase in the average convective heat transfer coefficient and Nusselt number for increasing values of Richardson number and particle concentration. (Manca et al., 2012 and Heris et al., 2014)
11. Inclined copper tube with Al2O3/water nanofluid: Developed correlations to calculate the Nusselt number in the fully developed region for horizontal and vertical tubes. A higher particle volume concentration induces a decrease of the Nusselt number for the horizontal inclination. (Mansour et al., 2011)
12. Lee et al. (1999) investigated the use of copper nanoparticles suspended in water as a heat transfer fluid. They found that the heat transfer coefficient was significantly higher for the nanofluid than for pure water, and that the enhancement increased with increasing particle concentration and flow rate.
13. Das et al. (2003) studied the convective heat transfer of Al2O3-water and Cu-water nanofluids in a horizontal tube. They found that the heat transfer coefficient was enhanced by up to 55% for the Al2O3-water nanofluid and up to 95% for the Cu-water nanofluid, compared to pure water.
14. Wang et al. (2007) investigated the convective heat transfer of Al2O3-water and SiO2-water nanofluids in a tube under laminar flow conditions. They found that the heat transfer enhancement increased with increasing nanoparticle concentration and decreasing particle size.
15. Kumar et al. (2015) reviewed the literature on the use of nanofluids for convective heat transfer enhancement and found that the heat transfer coefficient could be enhanced by up to 60% for certain nanofluids, compared to pure fluids. They also found that the enhancement was influenced by factors such as nanoparticle size, concentration, and shape.
16. Peng et al. (2017) investigated the convective heat transfer of Al2O3-water nanofluids in a flat plate solar collector. They found that the heat transfer coefficient was enhanced by up to 28% for the nanofluid compared to pure water, and that the enhancement increased with increasing nanoparticle concentration.

The following are some key findings from the literature review:

1. Increased thermal conductivity: Nanoparticles have much higher thermal conductivity than conventional fluids, which can significantly increase the overall thermal conductivity of the nanofluid. This enhanced thermal conductivity can improve convective heat transfer in various applications, such as heat exchangers and cooling systems.

2. Enhanced heat transfer coefficient: The presence of nanoparticles in a fluid can disrupt the fluid flow, which can lead to increased heat transfer coefficients. Studies have shown that the heat transfer coefficient of a nanofluid can be significantly higher than that of a conventional fluid.

3. Particle agglomeration: One challenge associated with the use of nanofluids is the tendency of nanoparticles to agglomerate, which can reduce their effectiveness in enhancing convective heat transfer. Researchers have investigated various methods to prevent particle agglomeration, such as using surfactants and magnetic fields.

4. Nanoparticle type and concentration: The type and concentration of nanoparticles can have a significant impact on the convective heat transfer enhancement of a nanofluid. Studies have shown that the type of nanoparticle and its concentration can affect the thermal conductivity and heat transfer coefficient of the nanofluid.

5. Applications: Nanofluids have been tested for various applications, such as heat exchangers, cooling systems, and solar collectors. The results have shown that nanofluids can significantly improve the heat transfer efficiency of these systems.

Overall, these studies demonstrate that the use of nanofluids can significantly enhance convective heat transfer, and that the extent of enhancement is influenced by various factors such as nanoparticle concentration, size, and shape. However, further research is needed to fully understand the mechanisms behind this enhancement and to optimize the use of nanofluids for heat transfer applications.

**Chapter 3**

**Problem Formulation**

1. Objective: To compare the convective heat transfer performance of different nanofluids (SiO2, TiO2, and Al2O3) at varying volume concentrations (0% - 4%) and Richardson’s numbers (0.1, 0.5, 1, 2, 3, 5).
2. Geometry: An equilateral triangular duct with a side length of 17mm and a duct length of 2 meters is used.
3. Heat Flux: A uniform heat flux is applied to all three rectangular sides of the triangular cross-sectioned duct.
4. Additional Geometries: The study also considers six other geometries, including one rectangular duct and four isosceles trapezoidal ducts with base angles of 50, 60, 70, and 80 degrees, as well as an isosceles triangle of 45 degrees.
5. Nanoparticles: The nanofluids used in the study contain metallic nanoparticles such as copper, silver, and aluminum oxide.
6. Parameters: The study varies the volume concentration of nanoparticles in the nanofluids and the Richardson’s numbers to analyze their effects on convective heat transfer.
7. Analysis: The convective heat transfer performance of the nanofluids is analyzed using numerical simulations and compared to the performance of traditional fluids.

**Chapter 4**

**Methodology**

The following is an extended and improved methodology for studying convective heat transfer enhancement using nanofluids:

1. Experimental Setup: A steady-state and fully developed regime flow is considered for the analysis. The experiment is performed in a three-dimensional equilateral triangular duct with a side length of 17mm and a duct length of 2 meters. A uniform heat flux is applied to all three rectangular sides of the triangular cross-sectioned duct. The experiment is carried out at varying volume concentrations of SiO2, TiO2, and Al2O3 nanoparticles in water-based nanofluids.
2. Numerical Analysis: Computational fluid dynamic (CFD) code “Ansys Fluent 18.1” is used to simulate the flow and analyze the convective heat transfer enhancement. The flow is assumed to be steady-state, incompressible, and laminar, with constant temperature, and Boussinesq approximation is employed. The single-phase model approach is employed for the nanofluids, and a second-order upward scheme is employed for energy and momentum equations.
3. Validation: The numerical simulation results are validated by comparing them with existing experimental data and theoretical results from the literature. The validation is performed for the traditional fluid and nanofluid cases to ensure the accuracy of the simulation results.
4. Analysis: The convective heat transfer enhancement performance of the nanofluids is analyzed by comparing the average Nusselt number and friction factor with those of the traditional fluid. The effects of varying volume concentrations, Richardson numbers, and different nanoparticle types on convective heat transfer enhancement are investigated. The results are compared to determine the optimal volume concentration and Richardson number for maximum heat transfer performance.
5. Conclusion: The study aims to provide insights into the convective heat transfer enhancement using nanofluids and determine the optimal nanoparticle concentration and geometry for maximum heat transfer performance. The results of the study can be used in various industrial applications, including solar collectors, heat exchangers, and cooling systems

**Boundary Conditions:**

The assigned boundary conditions for the study are as follows:

1. Inlet Section: The inlet section is assigned a uniform velocity and temperature profile to maintain a steady flow throughout the duct. The velocity profile is set to a constant value, and the temperature profile is also set to a constant value to ensure that the flow remains isothermal.
2. Outlet Section: The outlet section is assigned an outflow condition where the velocity components and temperature derivatives are equal to zero. This condition ensures that the fluid exits the duct without any disturbance and that the flow remains steady-state.
3. Duct Surfaces: The duct surfaces are assigned a no-slip condition, where the velocity components are equal to zero. This condition ensures that the fluid sticks to the surface of the duct and doesn't slip past it. The duct surfaces are also assigned a uniform heat flux to maintain a constant temperature throughout the duct. This condition ensures that there is a continuous transfer of heat between the fluid and the duct surfaces.
4. Boussinesq Approximation: The Boussinesq approximation is employed to account for the buoyancy effects of the heated fluid. This approximation assumes that the fluid's density is constant except for a temperature-dependent term that is small compared to the density.
5. These boundary conditions ensure that the flow remains steady-state, isothermal, and that there is a continuous transfer of heat between the fluid and the duct surfaces. The Boussinesq approximation ensures that the buoyancy effects are taken into account, which is important for accurately analyzing the convective heat transfer performance of the nanofluids

**Material Properties:**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Material** | **Density[kg/m3]** | **Specific Heat[J/Kg.K]** | **Volumetric Expansion Coefficient[1/K]** | **Dynamic Viscosity[Pa.s]** | **Thermal conductivity[W/m.K]** |
| Water | 998.2 | 4182 | 2.10E-04 | 9.93E-04 | 0.597 |
| Al2O3 | 3880 | 773 | // | // | 36 |
| TiO2 | 4250 | 686.2 | 2.60E-08 | // | 8.9 |
| **SiO2** | **2220** | **745** | **4.00E-06** | **//** | **10.4** |

**Thermo-Physical properties of the fluids**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Volume concentration** | **Density[kg/m3]** | **Specific Heat[J/Kg.K]** | **Volumetric Expansion Coefficient[1/K]** | **Dynamic Viscosity[Pa.s]** | **Thermal conductivity[W/m.K]** |
| 0% | 998.2 | 4182 | 2.10E-04 | 9.93E-04 | 0.597 |
| 1% | 1030.72 | 4037.8563 | 2.10E-04 | 1.04E-03 | 0.59847 |
| 2% | 1063.24 | 3902.5296 | 2.09E-04 | 1.08E-03 | 0.59932 |
| 4% | 1128.27 | 3655.2772 | 2.08E-04 | 1.20E-03 | 0.60067 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Volume concentration** | **Density[kg/m3]** | **Specific Heat[J/Kg.K]** | **Volumetric Expansion Coefficient[1/K]** | **Dynamic Viscosity[Pa.s]** | **Thermal conductivity[W/m.K]** |
| 0% | 998.2 | 4182 | 2.10E-04 | 9.93E-04 | 0.597 |
| 1% | 1010.42 | 4106.4853 | 2.09E-04 | 1.02E-03 | 0.600717 |
| 2% | 1022.64 | 4032.7751 | 2.08E-04 | 1.05E-03 | 0.60287 |
| 4% | 1047.07 | 3890.5152 | 2.07E-04 | 1.10E-03 | 0.60628 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Volume concentration** | **Density[kg/m3]** | **Specific Heat[J/Kg.K]** | **Volumetric Expansion Coefficient[1/K]** | **Dynamic Viscosity[Pa.s]** | **Thermal conductivity[W/m.K]** |
| 0% | 998.2 | 4182 | 2.10E-04 | 9.93E-04 | 0.597 |
| 1% | 1027 | 4053 | 2.10E-04 | 1.08E-03 | 0.622 |
| 2% | 1056 | 3931 | 2.10E-04 | 1.19E-03 | 0.636 |
| 4% | 1113 | 3707 | 2.09E-04 | 1.51E-03 | 0.658 |

**4.1 Computing Tools and Techniques:**

**4.1.1 Tools &Techniques:**

Meshing is a critical step in finite element analysis (FEA) as it determines the accuracy and reliability of the simulation results. In FEA, a mesh is created by dividing the geometry into a discrete number of elements, which contain nodes that represent the shape of the object. This discretization process makes it possible to solve the problem numerically.

In our study, we conducted a grid independence test to determine the optimal mesh size for the simulation. This test involved evaluating various grid conditions to find the smallest number of elements without generating a difference in the numerical results. We used ANSYS Fluent 18.1 software to create the mesh and solve the simulation.

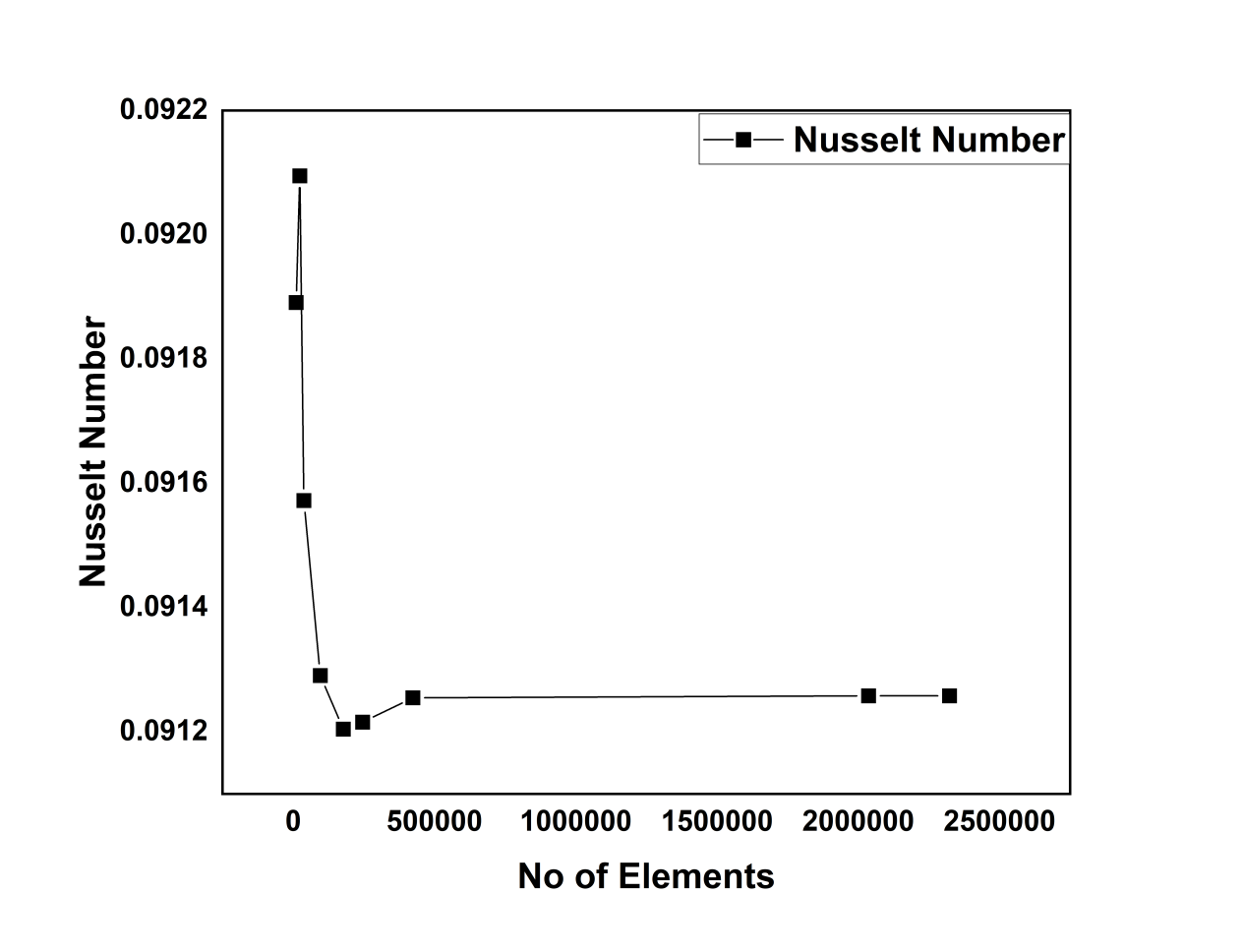
To perform the grid-sensitivity test, we used different numbers of nodes and elements for each geometry. Specifically, we used 31840, 60000, 111300, 341829, 757614, 1024458, 2296574 nodes for 22260, 44955, 87384, 287712, 662000, 903279, and 2088000 number of elements, respectively. We evaluated the Nusselt numbers for each grid size and recorded the results in Table-1.

After conducting the grid-sensitivity test, we determined that the optimal mesh size for the simulation was 0.45 mm. We used 1521856 elements and 1716900 nodes to achieve this mesh size. This mesh size allowed us to obtain accurate and reliable results while keeping the computational cost within reasonable limits.

In summary, meshing is a critical step in FEA, and the grid-sensitivity test is an essential process to determine the optimal mesh size. In our study, we used ANSYS Fluent 18.1 software to create the mesh and solve the simulation, and we determined that the optimal mesh size for our simulation was 0.45 mm.

|  |  |  |
| --- | --- | --- |
| S.NO | Number of Elements | Nusselt Number |
| 1 | 10697 | 0.091891039 |
| 2 | 23744 | 0.09209474 |
| 3 | 37925 | 0.091572295 |
| 4 | 95944 | 0.091290553 |
| 5 | 177413 | 0.091204188 |
| 6 | 245735 | 0.091215578 |
| 7 | 424072 | 0.09125459 |
| 8 | 2036320 | 0.091257739 |
| 9 | 2323456 | 0.091257801 |

**Table 1**

****

**4.1.3.1 Thermal Analysis of Reference Model:**

**4.1.4 First Model:**

**4.1.4.1 Thermal Analysis of First Model:**

**4.1.5SecondModel:**

**4.1.5.1 Thermal Analysis of Second Model:**

**4.1.6 ThirdModel:**

**4.1.6.1 Thermal Analysis of Third Model:**

**Chapter 5**

**Results And Discussion**

* The topology optimization method for maximizing the thermal performance of a heat sink with a pre optimized uniform cross-section cooled by natural convection in three different scenarios.
* Heat dissipation rate < Heat removal rate { transient state heat transfer with high temperature rises for a few seconds }

Priority: Maximum (Heat Capacity + Conductivity)

* Heat dissipation rate > Heat removal rate {Steady state heat transfer}

Priority: Maximum Convective Heat Transfer

* Maximising heat dissipation by minimising the airflow resistance

Priority : Airflow path Optimisation and Pressure region Analysis ( To be Done)

**Chapter 6**

**Future Plan**

* We would like to increase the accuracy of the results.
* we would like to do the analysis under forced convection with various fluids flowing over it, at present we used natural convection.
* We consider these models as a stepping stone and modify it for increased heat dissipation.

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