TEMPORAL EVOLUTION OF HEAT: TRANSIENT CONDUCTION ANALYSIS ON A SOLID SPHERE

[AE-608A] - HEAT TRANSFER IN AEROSPACE APPLICATIONS

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SUBMITTED BY

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KANPUR

1. OBJECTIVE:

This study utilizes ANSYS Fluent to simulate the transient heat transfer behavior within a solid sphere. The simulation aims to elucidate the temporal evolution of temperature and analyze the thermal response of the sphere under various boundary conditions.

2. INTRODUCTION:

Transient heat transfer analysis plays a crucial role in understanding thermal behavior in various engineering applications. This study investigates transient conduction heat transfer within a solid titanium sphere using ANSYS Fluent. The sphere, initially at a uniform temperature of 1200 K and with a radius of 20 mm, is subjected to a surrounding stationary air environment maintained at 250 K. This significant temperature difference establishes a driving force for heat transfer via conduction, prompting thermal energy to flow from the hot titanium sphere to the cooler air. The analysis aims to elucidate the temporal evolution of temperature within the sphere and explore the thermal response under these conditions. By analyzing the interplay between heat transfer rate and the materials' specific heat capacities, this study seeks to understand the rate of temperature change in both the sphere and the surrounding air.

3. METHODOLOGY:

3.1. GEOMETRY:

The geometry for this analysis was created within ANSYS Design Modeler. It consists of a solid titanium sphere with a radius of 20 mm surrounded by a fluid domain of air extending 2000 mm from the sphere's surface. In ANSYS Fluent, the sphere is designated as a wall, while the surrounding air is defined as the fluid region. As shown in figure 1.

3.2.MESHING:

To ensure accurate results, double precision will be employed for all calculations. The mesh will encompass both the solid titanium sphere and the surrounding air domain. A tetrahedral unstructured mesh will be utilized for efficient discretization of the geometry. This mesh type is well-suited for complex geometries and allows for good resolution near the sphere's surface, which is crucial for capturing the heat transfer process accurately. As shown in figure 2.

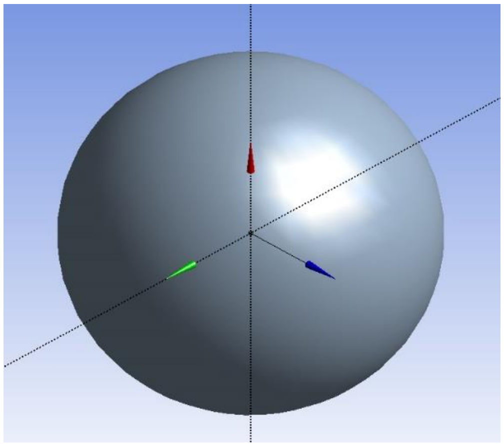


Figure 1: solid sphere and fluid domain.

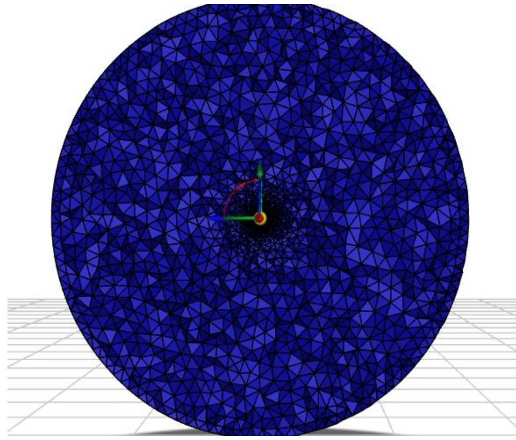


Figure 2: Volume mesh of a solid sphere and fluid domain.

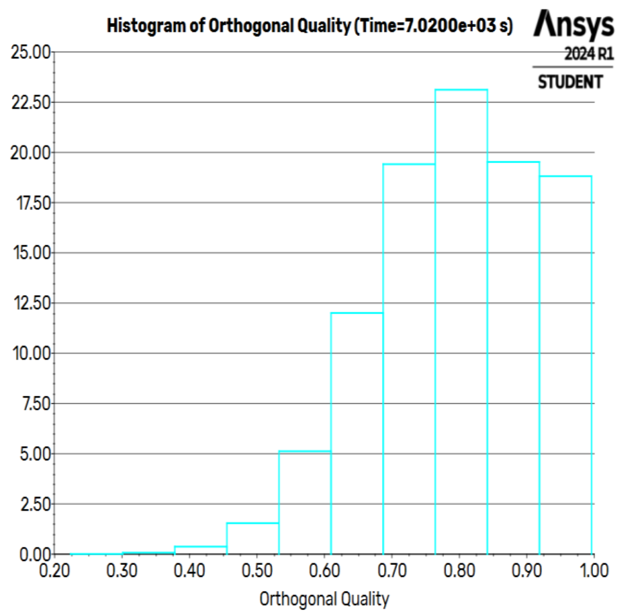
Mesh Size

Cells	Faces	Nodes
242838	516000	59421

Mesh Quality

Name	Type	Min Orthogonal Quality	Max Aspect Ratio
Fluid	Mixed Cell	0.22359329	17.585405
Sphere	Tet Cell	0.23608988	12.432358

Orthogonal Quality



3.3. SYSTEM INFORMATION:

Application	Fluent
Settings	3d, double precision, pressure-based, laminar, transient
Version	24.1.0-10184
Source Revision	5b3f9fb3c8
Build Time	Nov 22 2023 10:32:41 EST
CPU	AMD Ryzen 5 5625U with Radeon Graphics
OS	Windows

3.4 SIMULATION SETUP:

Physics:

Models

Model	Settings
Space	3D
Time	Unsteady, 2nd-Order Implicit
Viscous	Laminar
Heat Transfer	Enabled

Material Properties

- Fluid	
- air	
Density	1.225 kg/m^3
Cp (Specific Heat)	1006.43 J/(kg K)
Thermal Conductivity	0.0242 W/(m K)
Viscosity	1.7894e-05 kg/(m s)
Molecular Weight	28.966 kg/kmol
- Solid	

- titanium	
Density	4850 kg/m^3
Cp (Specific Heat)	544.25 J/(kg K)
Thermal Conductivity	7.44 W/(m K)

Cell Zone Conditions

- Fluid	
- fluid	
Material Name	air
Specify source terms?	no
Specify fixed values?	no
Frame Motion?	no
Mesh Motion?	no
Porous zone?	no
3D Fan Zone?	no
- Solid	
- sphere	
Material Name	titanium

Specify source terms?	No
Specify fixed values?	No
Frame Motion?	No
Mesh Motion?	No
Solid Motion?	No

Boundary Conditions

- Outlet	
- outlet	
Backflow Reference Frame	Absolute
Gauge Pressure [Pa]	0
Pressure Profile Multiplier	1
Backflow Total Temperature [K]	250
Backflow Direction Specification Method	Normal to Boundary
Backflow Pressure Specification	Total Pressure
Build artificial walls to prevent reverse flow?	no

Radial Equilibrium Pressure Distribution	no
Average Pressure Specification?	no
Specify targeted mass flow rate	no
- Wall	
- inner_sphere	
Wall Thickness [m]	0
Heat Generation Rate [W/m^3]	0
Material Name	titanium
Thermal BC Type	Coupled
Enable shell conduction?	no
Wall Motion	Stationary Wall
Shear Boundary Condition	No Slip
Convective Augmentation Factor	1
- inner_sphere-shadow	
Wall Thickness [m]	0
Heat Generation Rate [W/m^3]	0

Material Name	titanium
Thermal BC Type	Coupled
Enable shell conduction?	no
Convective Augmentation Factor	1

Reference Values

Area	1 m^2
Density	1.225 kg/m^3
Enthalpy	0 J/kg
Length	1 m
Pressure	0 Pa
Temperature	288.16 K
Velocity	1 m/s
Viscosity	1.7894e-05 kg/(m s)
Ratio of Specific Heats	1.4
Yplus for Heat Tran. Coef.	300
Reference Zone	fluid

Solver Settings

- Equations	
Flow	True
Energy	True
- Numerics	
Absolute Velocity Formulation	True
- Unsteady Calculation Parameters	
Number of Time Steps	500
Time Step Size [s]	20
Max Iterations/Time Step	20
- Under-Relaxation Factors	
Pressure	0.3
Density	1
Body Forces	1
Momentum	0.7
Energy	1

- Pressure-Velocity Coupling	
Type	SIMPLE
- Discretization Scheme	
Pressure	Second Order
Momentum	Second Order Upwind
Energy	Second Order Upwind
- Solution Limits	
Minimum Absolute Pressure [Pa]	1
Maximum Absolute Pressure [Pa]	5e+10
Minimum Static Temperature [K]	1
Maximum Static Temperature [K]	5000

Run Information

Number of Machines	1
Number of Cores	2
Case Read	10.114 seconds
Data Read	0.597 seconds
Virtual Current Memory	1.79449 GB

Virtual Peak Memory	1.80346 GB
Memory Per M Cell	3.64751

Solution Status
Flow Time: 7020, Time Step: 351

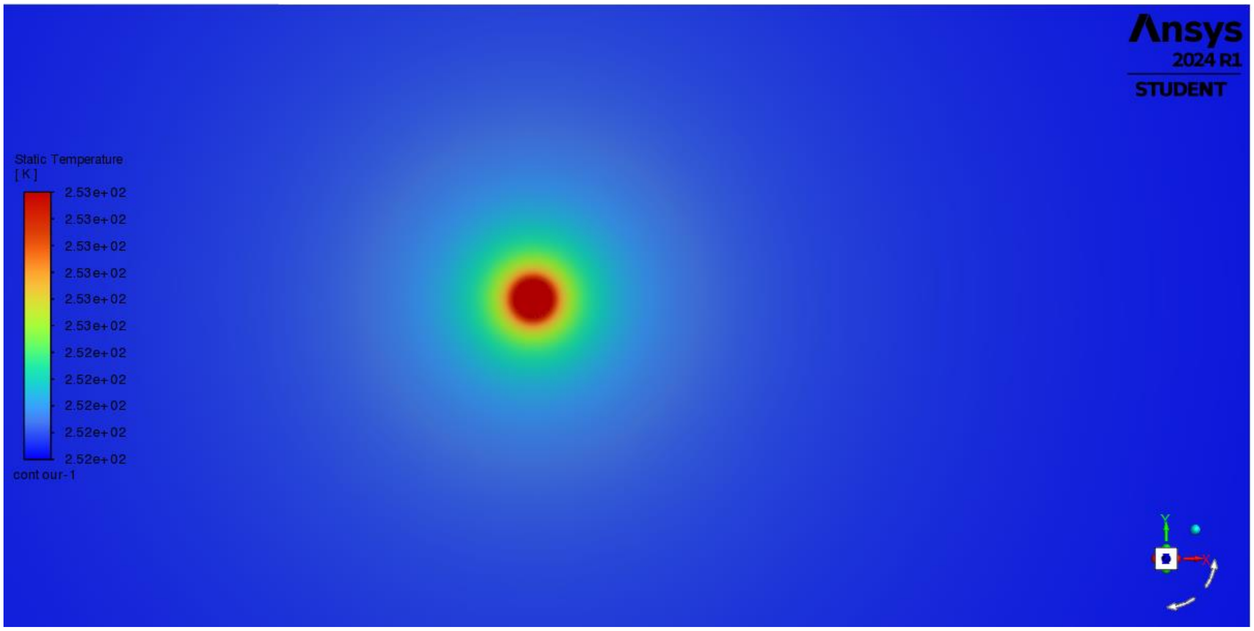
	Value	Absolute Criteria	Convergence Status
continuity	0	0.001	Converged
x-velocity	0	0.001	Converged
y-velocity	0	0.001	Converged
z-velocity	0	0.001	Converged
energy	4.300673e-10	1e-06	Converged

4. RESULT PLOTS & ANALYSIS:

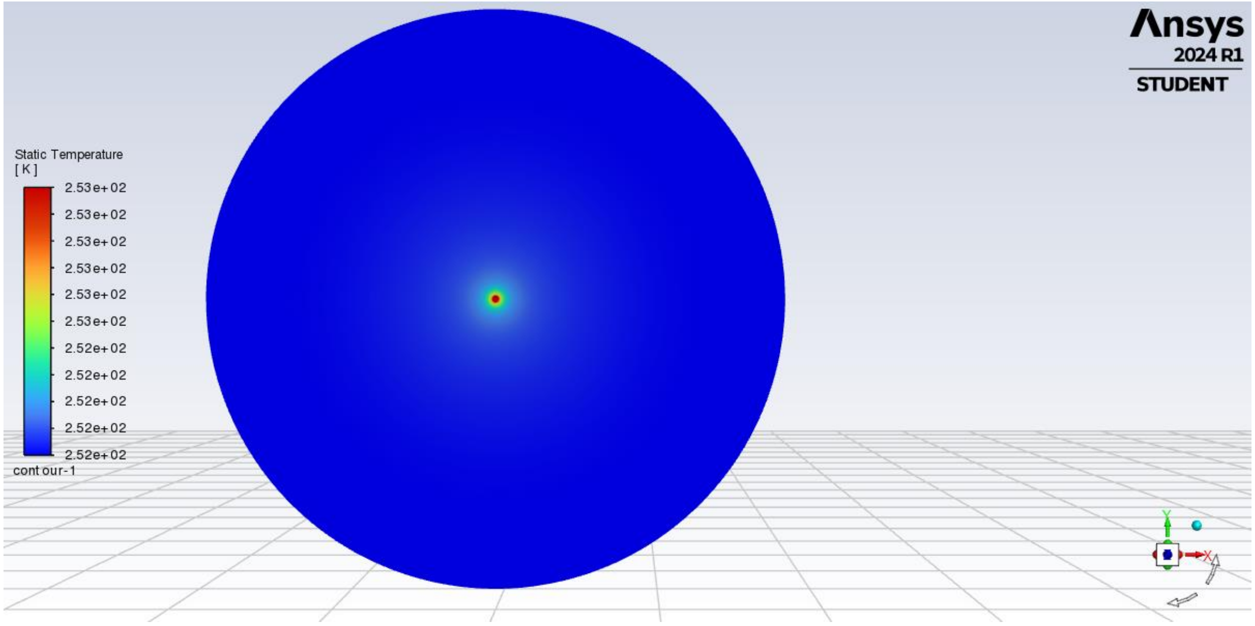
Time & Step Size

Number of Time Steps	500
Time Step Size [s]	50
Max Iterations/Time Step	20

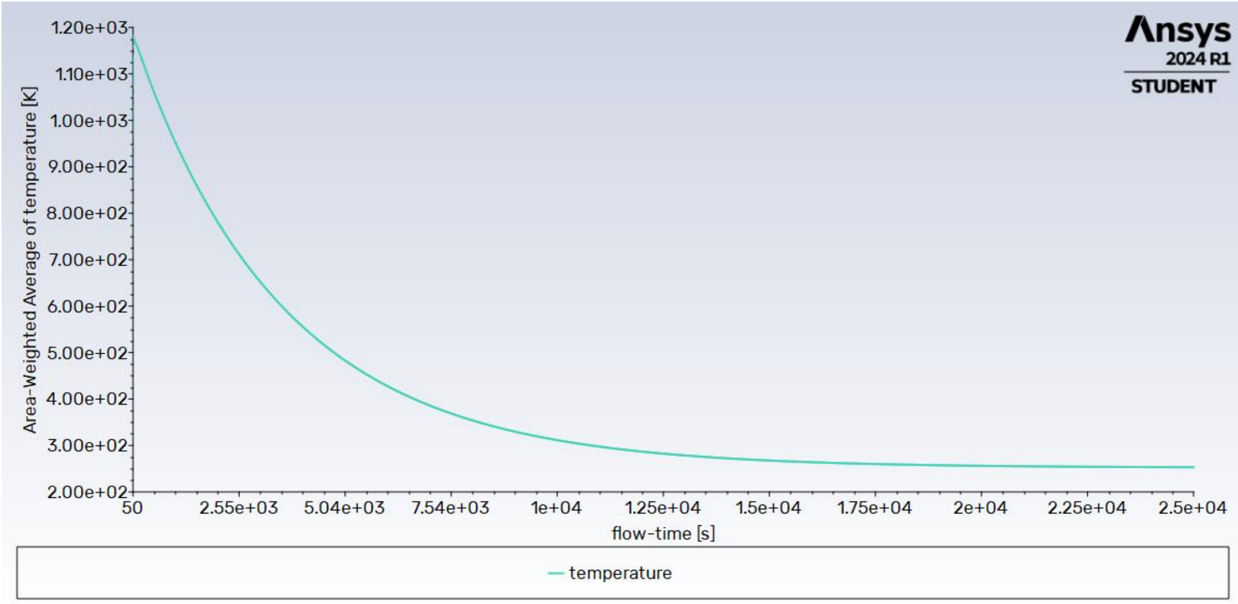
Plots & Pictures:



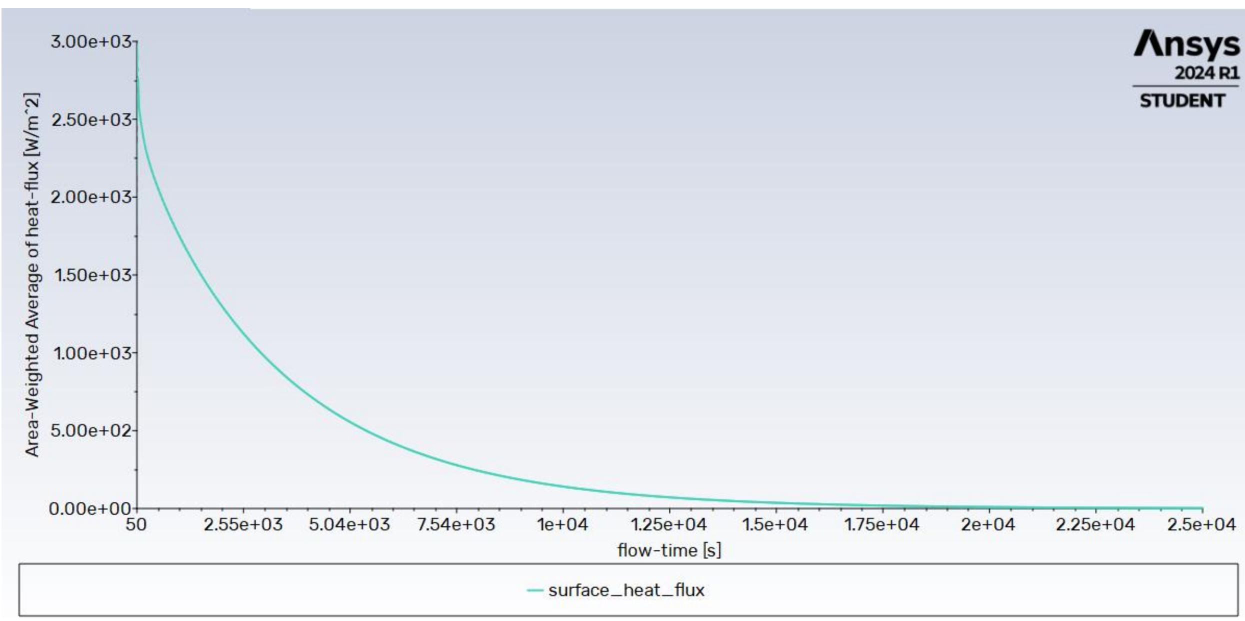
Pic.1: Closer view of the spherical metal body.
The image represents temperature distribution, with different colors indicating varying temperature levels.
It's interesting because it provides visual insights into thermal characteristics and behaviors.



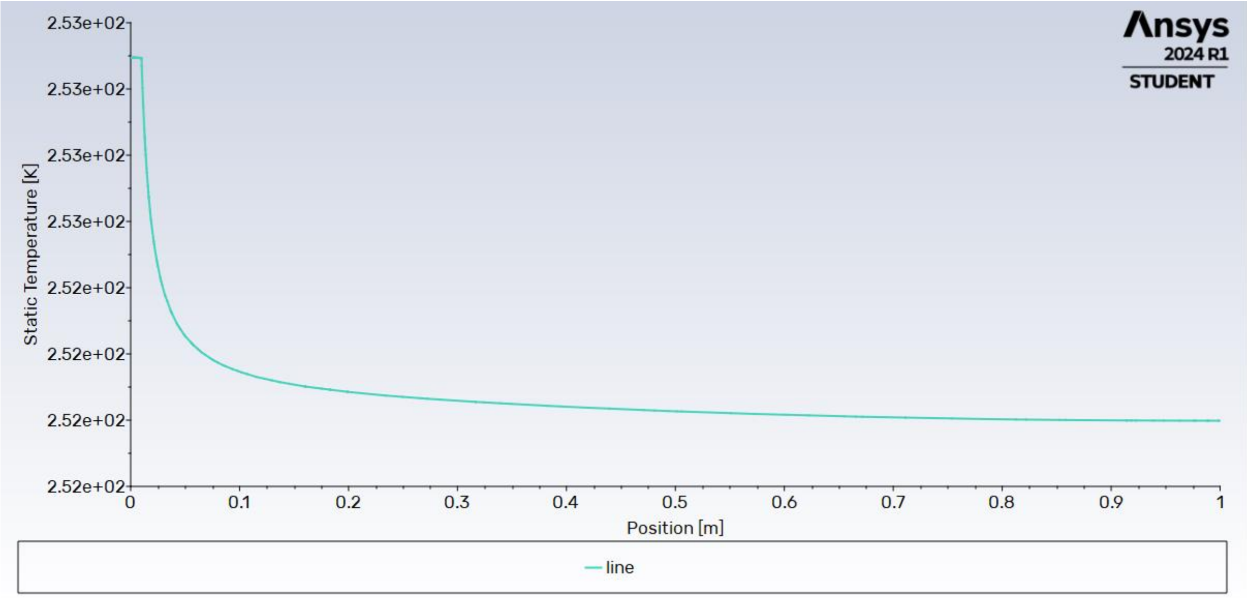
Pic.2: The spherical metal body and air enclosure.
The visualization uses different colors to represent varying temperatures. This allows for the analysis of heat dispersion or concentration in the studied object.



Plot.1: Shows the **transient temperature response** of the solid titanium sphere. The x-axis represents time, and the y-axis represents the average temperature within the sphere. The downward trend suggests that the sphere is **cooling down** over time. This is due to heat transfer from the hotter sphere to the cooler surrounding air.



Plot.2: shows a line graph with heat flux on the y-axis and time on the x-axis.
The line trends slightly downwards, but overall seems relatively flat, indicating that the heat flux is relatively constant over time.



Plot.3: shows a line graph with static temperature on the y-axis and position on the x-axis. The x-axis label cut off but it represents a distance along a line from diameter of inner metallic sphere to outer surface of enclosure within the geometry. The line starts at a higher temperature and trends downward, indicating a temperature gradient.

Analysis

Upon completion of the analysis, the following results will be obtained:

- Temperature distribution within the solid sphere at different time steps. In Plot.1 it can be seen that the reduction in temperature of solid sphere from 1200 K to 252.54 K over time by conduction heat transfer between solid sphere and stationary fluid domain. Pic.1&2 temperature contour provides insights into the spatial distribution and variation of the variable within the domain.
- Heat transfer flux rate decreases from the initial heat transfer flux rate of 3 kW/m^2 shown in Plot.2.
- At the end of the calculation temperature of fluid domain at its outlet was raised to 250K from 252.54 K. The effect of temperature of solid sphere to enclosure is negligible initially. As shown in Plot.3.

5. CONCLUSION:

This transient conduction heat transfer analysis, conducted using ANSYS Fluent on a solid titanium sphere, has yielded valuable insights into the dynamic thermal behavior of the system. The simulation demonstrates the decrease in sphere temperature (from 1200 K to 252.54 K) and the corresponding increase in air temperature as heat transfers from the sphere to the surrounding air. This process eventually reaches a steady state, characterized by thermal equilibrium between the sphere and the air.

The analysis highlights the impact of both air's low thermal conductivity and the solid-fluid interface on the rate of heat transfer. However, despite this limitation, air's favorable properties like low density and chemical inertness can make it a suitable coolant in specific applications. By studying the temporal evolution of temperature, this work offers a deeper understanding of the sphere's response to transient heat inputs or changes in boundary conditions.

Future studies could explore the influence of various transient boundary conditions or material properties on the sphere's transient heat transfer behavior. This could involve investigating different cooling fluids, varying sphere sizes, or introducing natural convection effects.