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Overall Objective

This report is structured into two main sections. The first section conducts a steady-state analysis of heat transfer in a pipe to identify the critical insulation radius, with the goal of optimizing insulation thickness to minimize heat loss and enhance thermal efficiency. The second section explores transient heat analysis, examining the temperature response of a pipe to thermal shock.

Assumptions

In part A, we assume steady-state heat transfer.

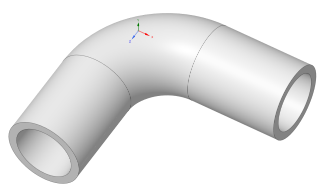
Radiative heat transfer is considered negligible across all analyses.

The specific heat and density of cast iron, along with the properties of the insulator, are assumed constant. However, the thermal conductivity of cast iron varies with temperature.

Furthermore, the thermal contact resistance at the interface between the metal and the insulation is considered negligible.

Geometry

Figure 1 shows the geometry of the pipe analyzed in here, which has a 90-degree bend. Inside and outside diameters are 70 mm and 90 mm, respectively.



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Material Data

The pipe is made of cast iron, with a density of 7200 kg/m^3, specific heat of 447 J/kg-C, and variable thermal conductivity, as given in below table.

The insulation material has a density of 2500 kg/m^3, specific heat of 840 J/kg-C, and thermal conductivity of 0.2 W/m-C.

Table of Properties Row 3: Isotropic Thermal Conductivity

	A	B
1	Temperature (C)	Thermal Conductivity (W m^-1 C^-1)
2	20	51.6
3	100	50.8
4	200	49.8
5	300	48.8
6	400	47.8
7	500	46.8
*		

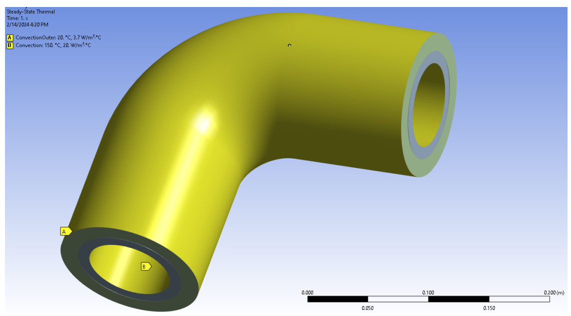
Boundary Conditions

In the Ansys Steady State Thermal program, the following boundary conditions were applied to both the inside and outside surfaces of the pipe:

- Convection of 3.7 W/m²°C is applied to the outside surface.
- The pipe ends are assumed to be adiabatic.
- For steady-state analysis (part A), convection of 20 W/m²°C at 150°C is applied to the inside surface, and the ambient temperature is 20°C.
- For transient analysis (part B), a step-applied convection shock of fast-moving steam with a convection of 50 W/m²°C at 150°C is applied to the inside surface, and the maximum outside temperature is 20°C.

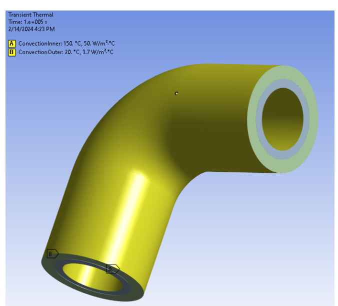
Part A:

Below figure shows the boundary conditions applied in part A for pipe with different thicknesses of insulation:



Part B:

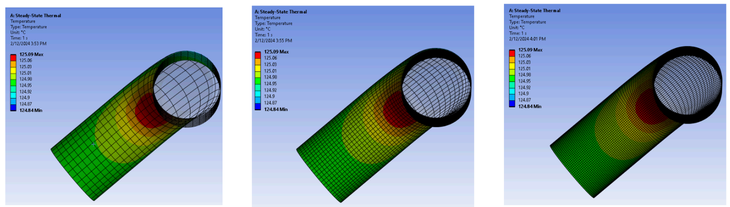
Below figure shows the boundary conditions applied in part B for pipe with insulation thickness of 15 mm:



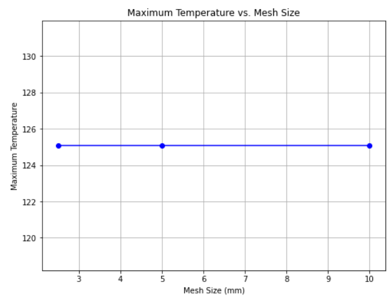
Mesh Convergence Study

To ensure convergence of the solution, the steady state heat analysis was conducted for mesh sizes of 10 mm, 5 mm, and 2.5 mm. It was observed that the results converged with a mesh size of 5 mm. Below figure depicts the value of temperature of the pipe for the three different mesh sizes utilized for the convergence study.

Mesh size = 10 mm   Mesh size = 5 mm   Mesh size = 2.5 mm



The above results show that both mesh sizes of 10 mm and 5 mm are fine enough to achieve convergence. Below figure also shows the convergence results:



The mesh size of 5 mm has been picked for the rest of the calculations.

Results:

Part A:

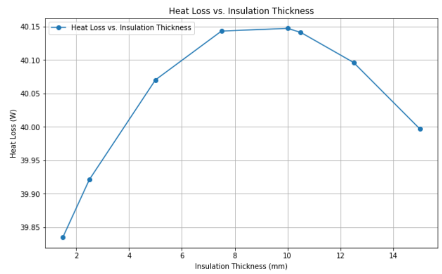
Steady-state heat analysis for different thicknesses of insulations was conducted, and below table shows the heat loss in the outer surface of the insulation for different thicknesses:

Insulation Thickness (mm)	1.5	2.5	5	10	15
Heat Loss (W)	39.835	39.921	40.07	40.147	39.997

After evaluating the above table, we realize that critical radius of thickness is a value in the range of 5mm to 15 mm. Therefore, we narrow down this range, and find the values of heat loss for below radiuses of thickness:

Insulation Thickness (mm)	7.5	12.5	10.5
Heat Loss (W)	40.143	40.096	40.141

Below plot shows amount of heat loss for different thicknesses of insulation:



Therefore, the critical thickness of insulation, where heat loss becomes maximum is the 10 mm thickness of insulation.

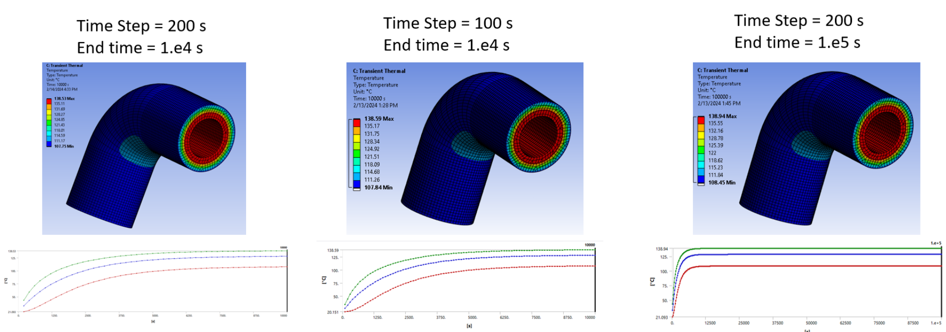
B) transient heat analysis:

First, with set the “Analysis Setting” with Time Step = 200 s, and Step End time of 1.e4 s. Below table shows the table of “Analysis Setting”

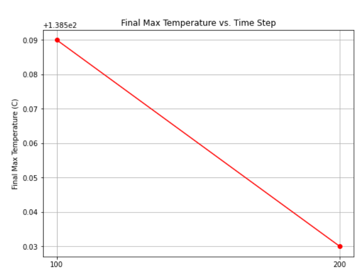
Details of "Analysis Settings"

Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	10000 s
Auto Time Stepping	Off
Define By	Time
Time Step	200. s
Time Integration	On

Below figure shows the results of this analysis for minimum, maximum, and average temperature of the body:

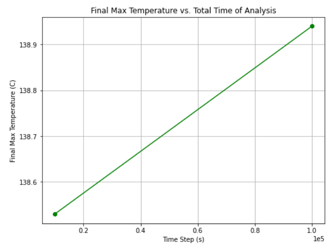


Below plot shows the results of maximum temperature of the body after reach a steady temperature with different time steps in the solver:



We can see that the difference in the result is less than 0.04% of the maximum temperature. Therefore, the time step of 200 s is enough for the convergence in the transient heat analysis results.

Also, below plot shows the plot for the maximum temperature with time step of 200 s after passing 1.e4 s and 1.e5 s.



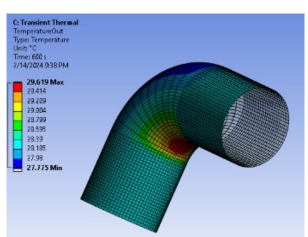
Again, we see that the difference in solving for 1.e4 seconds and 1.e5 seconds is less than 0.3% of the maximum temperature. Therefore, we conclude that after 1.e4 seconds it is safe to say we have the final temperature of the transient system.

Now, with time step of 200 s, we calculate the maximum temperature on the outside of the insulation after 600 s (10 minutes), 1.e4 s (167 minutes), and 5400 s (90 minutes). Then, we increase the analysis time until we satisfy the steady state condition.

Analysis Time (minutes)	10	167	90	91	92	95	94
Max Temp (°C)	29.62	113.53	106.93	107.15	107.39	108.01	107.79

Since 108.01 > 0.95*113.53, it takes 95 minutes for this system to reach steady state conditions.

The maximum temperature on the outside of the insulation at 10 minutes is also plotted as below:



Conclusion

The critical radius, at which the heat loss from the insulation surface peaks, occurs at an insulation thickness of 10 mm, corresponding to an outside insulation surface radius of 55 mm. Furthermore, the transient heat analysis reveals that the system reaches a steady state after 95 minutes, determined by considering 95% of the final temperature as the point at which steady state is achieved.