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Overall Objective

The objective is to perform a steady-state thermal analysis of a curved pipe transporting steam. Our focus is on determining the maximum outside surface temperature of the pipe and assessing the rate of heat loss from its exterior surface. Subsequently, we will investigate the thermal impact of incorporating a foam insulator on the outer surface of the pipe.

Assumptions

For all analyses presented herein, we assume steady-state thermal conditions and negligible radiative heat transfer. Additionally, the thermal properties are assumed to remain constant, and conductive heat transfer is considered linear. Furthermore, for Part C of the calculations (as described later in the document), the thermal contact resistance at the interface between the metal and the insulation is considered negligible.

Geometry

Figure 1 illustrates the geometry of the curved pipe under analysis.

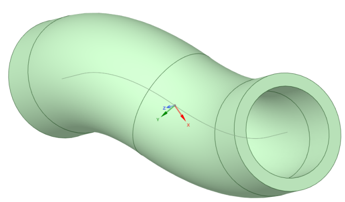


Figure 1 Geometry of the curved line.

Inside and outside diameters are 70 mm and 90 mm, respectively.

Material Data

The pipe is constructed from cast iron with a thermal conductivity of 52 W/m°C.

Additionally, a foam insulation material with a thermal conductivity of 0.2 W/m°C is utilized in Part C of the analysis.

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 20 W/m²°C at 155°C is applied to the inside surface.
- The ambient temperature is maintained at 20°C.
- The pipe ends are assumed to be adiabatic.

After configuring the geometry, material properties, and boundary conditions, the analysis was conducted in three distinct parts: Part A, Part B, and Part C. The specifics of each part are described below.

Part A:

It's assumed that pipe is not insulated, and the outside convection coefficient is 3.8 W/m²°C. Figure 2 shows the boundary conditions used in part A.

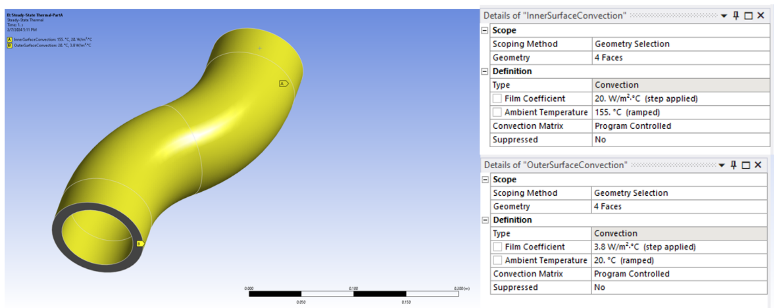


Figure 2 Boundary conditions in part A

Part B:

The outside surface of the pipe is insulated with a 5 mm layer of foam. It is then assumed that the total heat resistance (R_{total}) resulting from the insulation and the heat resistance from external surface convection act in series, as illustrated in Figure 3.

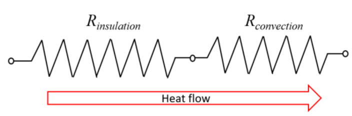


Figure 3 Total heat resistance

This means $R_{total} = R_{insulation} + R_{convection}$

This results in $R_{total} = 0.29/A$ where A is the total exterior surface area of the pipe. The equivalent exterior convection coefficient (h_{eq}) is easily determined from

heq = $1/(R_{total}\ A) = 3.4$ W/m²°C

which accounts for the added insulation and replaces the exterior convection coefficient used in Part A. Figure 4 shows the boundary conditions used in part B.

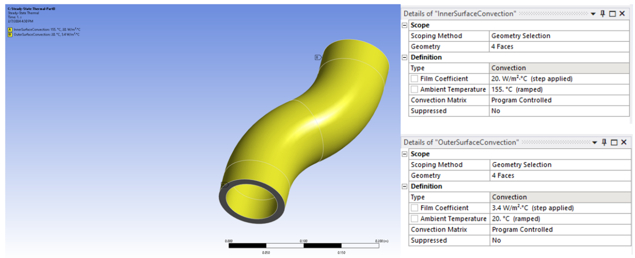


Figure 4 Boundary conditions in part B

Part C:

The outside surface of the pipe is insulated with a 5 mm layer of foam. Instead of approximating an equivalent convection film coefficient, this time the 5-mm thick insulation has been explicitly modeled. In doing so, a second part has been added to the given model, and foam insulation has been assigned to this part. The convection coefficient is 3.8 W/m²°C and is applied to the outside surface of the insulation, while the outside ambient temperature remains at 20°C. Figure 5 illustrates the boundary conditions utilized in Part C.

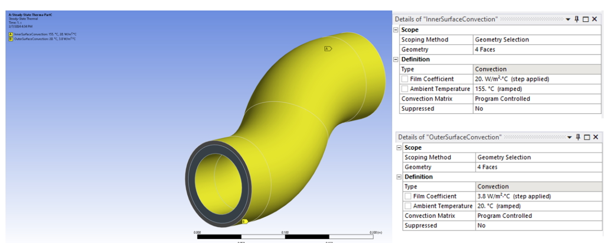


Figure 5 Boundary conditions in part B

Two components of analysis (cast iron pipe and foam insulator) for part C has been shown in Figure 6.

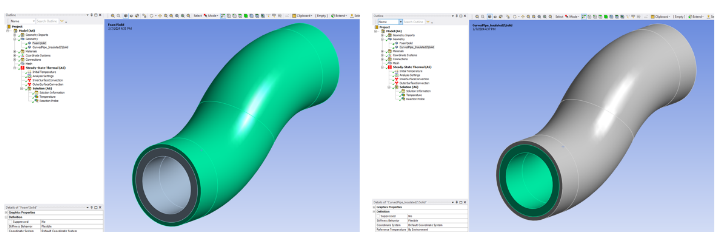


Figure 6 Two components used in the analysis

Mesh and Solution Setup

First, we conduct the mesh convergence study. To ensure convergence of the solution, the calculations were repeated with a finer mesh size of 0.0025 m. It was observed that the results converged with a mesh size of 0.005 m. Figure 7 depicts the two different mesh sizes utilized for the convergence study.

Mesh size = 0.005 Mesh size = 0.0025

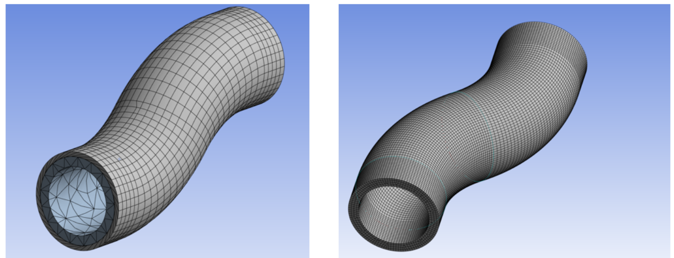


Figure 7 Two different mesh sizes for convergence study

The results of the pipe temperature in Part A are displayed for both mesh sizes of 0.005 and 0.0025 in Figure 8.

Mesh size = 0.005 Mesh size = 0.0025

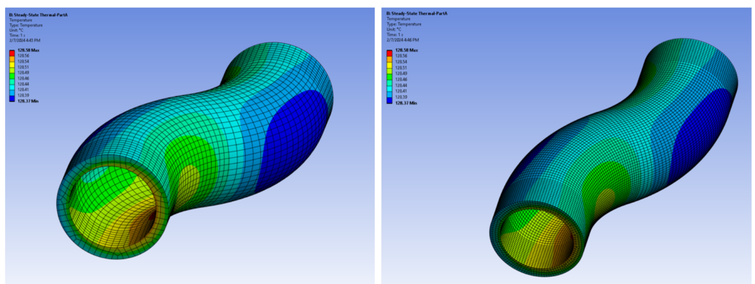


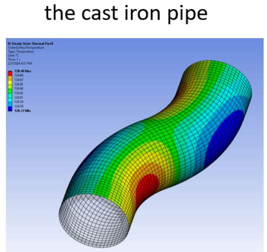
Figure 8 Temperature of the pipe for two different mesh sizes

Figure 8 demonstrates that the temperature has converged, and thus, we will utilize a mesh size of 0.005 for the remainder of this report.

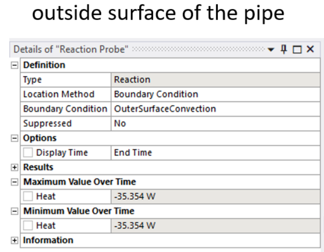
Results

The outside surface temperature and the heat loss off the outside surface for Part A are illustrated in Figure 9.

Outside surface temperature of the cast iron pipe



Rate of heat loss off the outside surface of the pipe



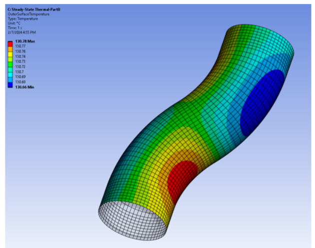
Details of "Reaction Probe"

Definition	
Type	Reaction
Location Method	Boundary Condition
Boundary Condition	OuterSurfaceConvection
Suppressed	No
Options	
Display Time	End Time
Results	
Maximum Value Over Time	
Heat	-35.354 W
Minimum Value Over Time	
Heat	-35.354 W
Information	

Figure 9 Outside surface temperature and the heat loss off the outside surface for part A

Outside surface temperature and the heat loss off the outside surface for part B is shown in Figure 10

Outside surface temperature of the cast iron pipe



Rate of heat loss off the outside surface of the pipe

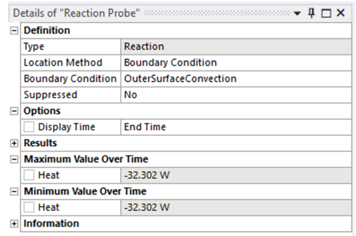
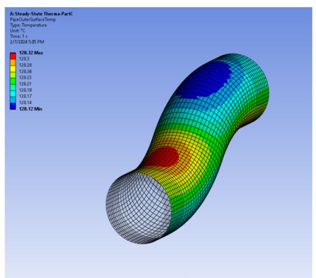


Figure 10 Outside surface temperature and the heat loss off the outside surface for part A

Outside surface temperature and the heat loss off the outside surface for part c is shown in Figure 11

Outside surface temperature of the cast iron pipe



Rate of heat loss off the outside surface of the pipe

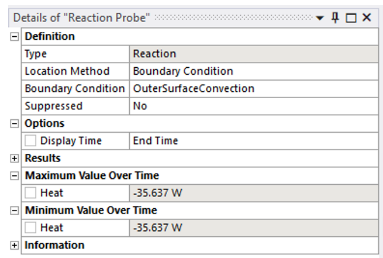


Figure 11 Outside surface temperature and the heat loss off the outside surface for part A

Table 1 shows summary of the results:

Table 1 Summary of the results

Part ID	Outside surface temperature of the cast iron pipe (°C)	Rate of heat loss (W)
Part A	128.5	35.4
Part B	130.8	32.3
Part C	128.3	35.6

Conclusion

As illustrated in the table above, the rate of heat loss in Part B is notably lower than in Part C. This difference is primarily due to the presence of insulation, which effectively reduces the rate of heat loss.

Moreover, the heat loss observed in Part C closely resembles that of Part A and surpasses that of Part B. This can be attributed to the application of a higher convection coefficient over a larger surface area in Part C compared to Part B. Additionally, in comparison to Part A, Part C exhibits the same convection coefficient but over a larger surface area (with a diameter of 100 mm as opposed to 90 mm), which results in higher rate of heat loss in part C. Also, it is important to note that the added insulation thickness is below the critical radius of insulation.