25-650: Applied FEA
Assignment 1
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Due: 2/7/2024

Overall Objective

The goal was to determine the max temperature and heat loss of a cast iron pipe carrying steam under multiple insulation conditions (no insulation, insulation via modified convection coefficient, and insulation via physical insulation).

Assumptions

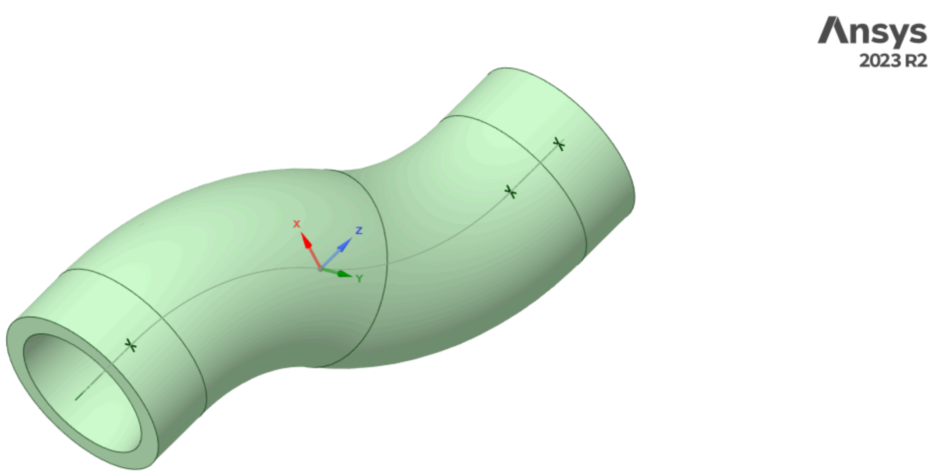
For all situations below, it is assumed that the heat transfer occurs at steady state, thermal properties are constant, radiation can be ignored, and contact resistance between metal and insulation is negligible (for physical modeling of insulation).

Geometry

A curved pipe was created in SpaceClaim, as a curved hollow cylinder with these dimensions:

- Inner diameter: 70 mm
- Outer diameter: 90 mm
- Outer Surface Area (ignoring pipe end faces): 85809.0 mm^2

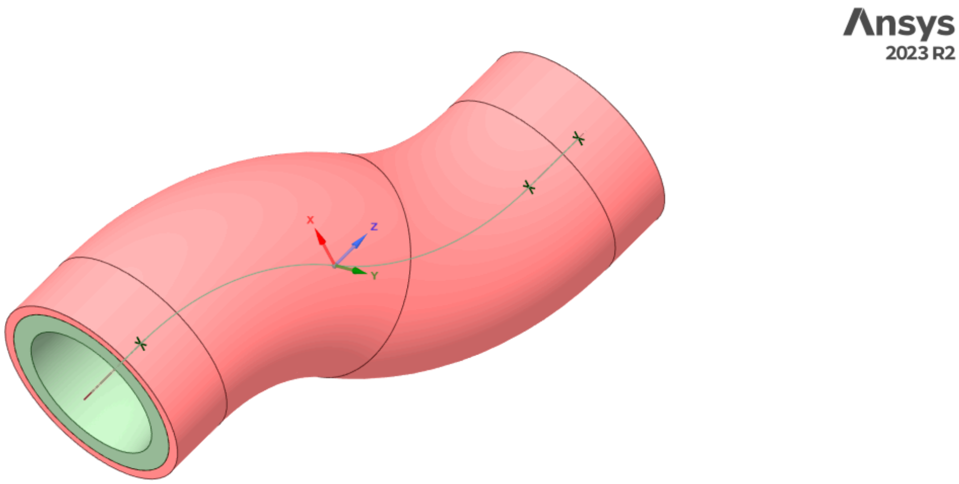
The resulting geometry is shown below:



For the physical modeling of the foam, an outer layer was added with dimensions:

- Inner diameter: 90 mm
- Outer diameter: 100 mm
- Outer Surface Area (ignoring pipe end faces): 95343.4 mm^2

The resulting geometry is shown below:



Material Data

The pipe was made of cast iron which has an isotropic thermal conductivity of 52 W/m-C and the insulation was made of foam which has an isotropic thermal conductivity of 0.2 W/m-C.

Boundary Conditions

In the Ansys Steady State Thermal program, the following boundary conditions were applied for all of the three simulation cases:

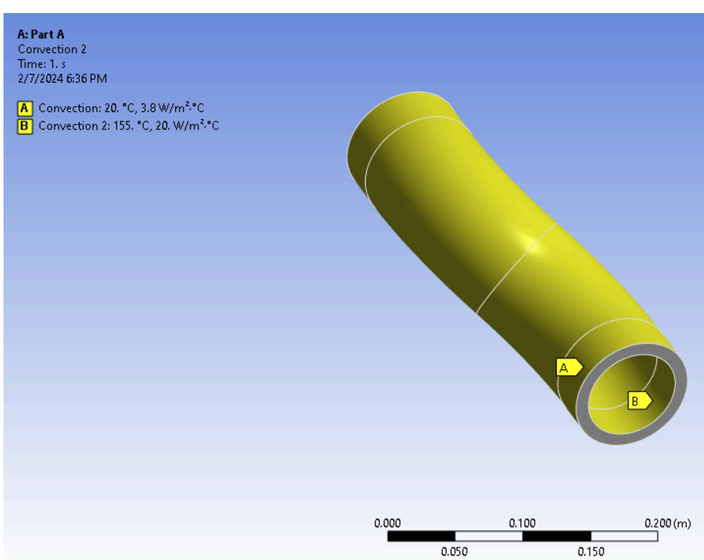
- Convection condition of 155 deg C, 20. W/m^2-C at inside faces of the pipe
- Adiabatic condition at end faces of pipe (default)

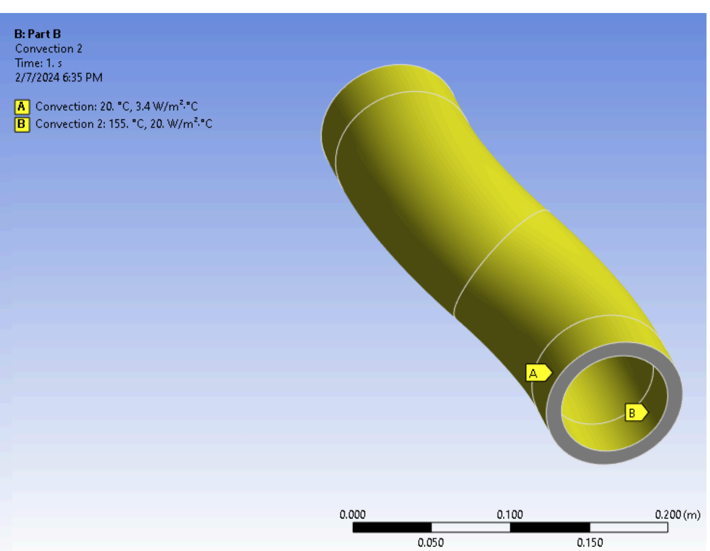
For Part A (no insulation):

- Convection condition of 20 deg C, 3.8 W/m^2-C at outside faces of the pipe

For Part B (modified convection coefficient insulation):

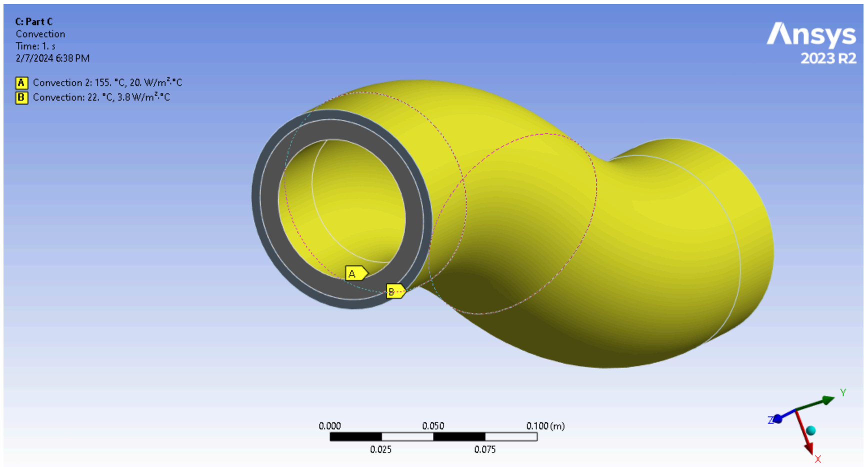
- Convection condition of 20 deg C, 3.4 W/m^2-C at outside faces of the pipe





For Part C (physical insulation):

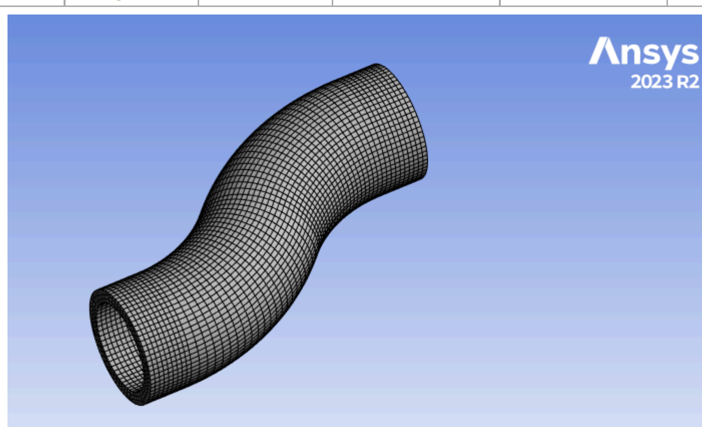
- Convection condition of 20 deg C, 3.8 W/m^2-C at outside faces of the insulation



Mesh and Solution Setup

Three meshes were generated for Part A with default settings and element sizes of 4mm, 20mm, and 50mm respectively. There were small observed differences between results between 4mm and 20mm as shown below, thereby indicating that the mesh is converged. However, the 4mm mesh (shown below) was not excessively computationally intensive, so it was used for the remainder of the simulations.

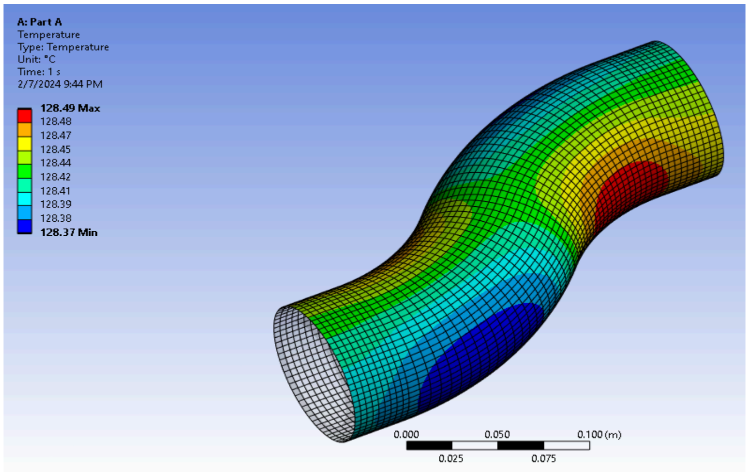
	Nodes	Elements	Temperature (°C)		Total Heat Flux (W/mm²)	
			Minimum	Maximum	Minimum	Maximum
Solution 1: 02/07/2024 04:59 PM	59,283	19,530	128.37	128.58	4.1085e-004	5.417e-004
Solution 2: 02/07/2024 05:21 PM	4,382	1,872	128.37	128.58	4.0496e-004	5.4083e-004
Solution 3: 02/07/2024 05:25 PM	2,041	882	128.37	128.59	3.904e-004	5.7711e-004



For all three simulation cases, a reaction probe was created to measure heat lost through the convection at the outermost surface of the pipe/insulation (4 faces). Additionally, max temperature was measured for the outer surface of the metal pipe (4 faces). Default conditions were otherwise used.

Results

Part A (no insulation):

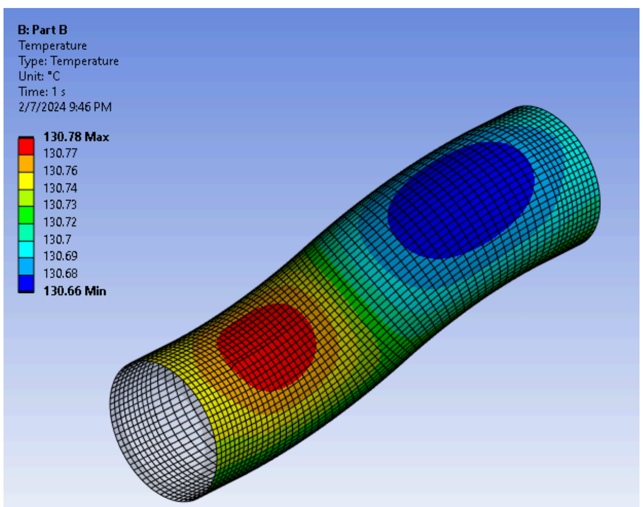


Details of "Reaction Probe"

Definition	
Type	Reaction
Location Method	Boundary Condition
Boundary Condition	Convection
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	

The outside surface of the metal pipe had a max temperature of 128.5 deg C and the overall heat lost from the convection at the outermost surface was -35.4 W.

For Part B (modified convection coefficient insulation):



Details of "Reaction Probe"

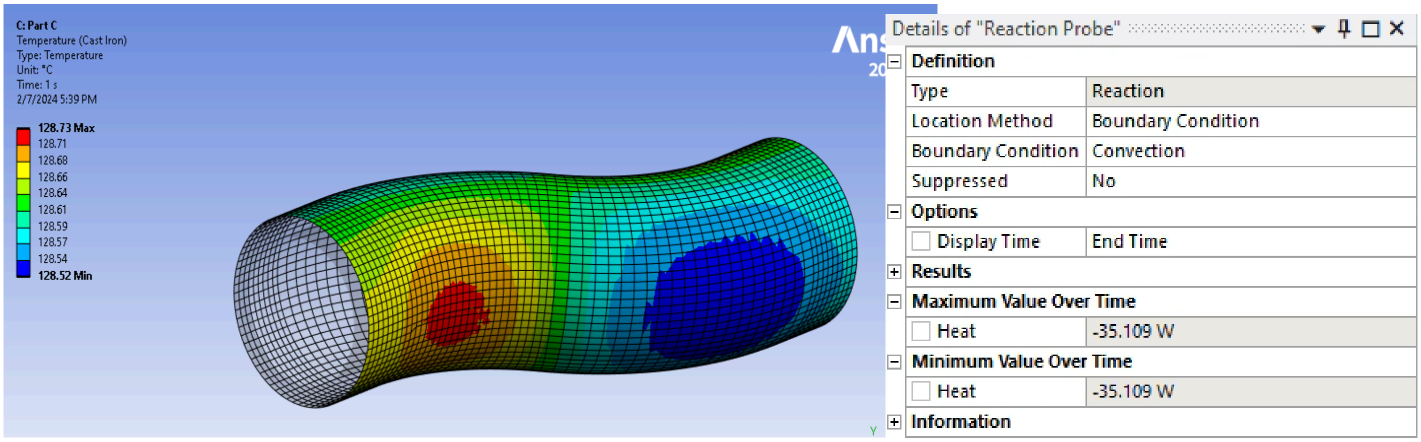
Definition	
Type	Reaction
Location Method	Boundary Condition
Boundary Condition	Convection
Suppressed	No
Options	
Display Time	End Time
Results	
Maximum Value Over Time	
Heat	-32.302 W
Minimum Value Over Time	
Heat	-32.302 W
Information	

The outside surface of the metal pipe had a max temperature of 130.8 deg C and the overall heat lost from the convection at the outermost surface was -32.3 W. The heat loss was lower than Part A because the convection coefficient of the surface was lower (3.4 vs 3.8 W/m^2-C) meaning less heat was transferred to the outside air. The equivalent convection coefficient was derived from the equations below using the metal pipe/foam thickness and material properties.

$$R(tot) = \frac{L}{kA} + \frac{L}{kA} = \frac{0.01m}{52\frac{W}{m\cdot C}\cdot 0.085809m^2} + \frac{0.005m}{0.2\frac{W}{m\cdot C}\cdot 0.085809m^2} = \frac{0.29}{A}$$

$$h\,(eq) = \frac{1}{R(tot)\cdot A} = \frac{1}{0.29} = 3.4\frac{W}{m^2\cdot C}$$

For Part C (physical insulation):



The outside surface of the metal pipe had a max temperature of 128.7 deg C and the overall heat lost from the convection at the outermost surface was -35.1 W. Compared to Part A, it makes sense that the heat loss is similar because although the foam insulation has a much lower isotropic thermal conductivity than the metal, the surface area for convection is much higher. The thickness of the insulation must be just above the critical thickness (the point at which additional insulation thickness begins to decrease heat loss). Compared to Part B, it also makes sense that the heat loss is higher because of the greatly increased surface area. It seems like using the equivalent convection coefficient is not a valid simulation strategy because it neglects physical increases in surface area due to the insulation.

Configuration	Outer Surface Area (mm^2)	convection coefficient of Outer Surface (W/m^2-C)	Heat Loss from Outer Surface (W)	Max Temperature (C)	Materials used
A (none)	85809.0	3.8	-35.4	128.5	Cast Iron (52 W/m-C)
B (coefficient change)	85809.0	3.4	-32.3	130.8	Cast Iron (52 W/m-C)
C (physical foam)	95343.4	3.8	-35.1	128.7	Cast Iron (52 W/m-C) and Foam (0.2 W/m-C)

Conclusion

Overall, the results of the simulations make sense given the conditions used. From these simulations, it is clear that equivalent convection coefficients should not be used in cases where the surface area for convection increases. Instead, a model should be used where physical foam is added like in Part C to more accurately simulate real world results.