# 25-650: Applied FEA
# Assignment 2
# Ryan Nagle
# Due: 2/14/2024

## Overall Objective

The goal was to analyze a cast iron pipe carrying steam at steady state and transient. During steady state, the objective was to computationally determine the critical radius of the insulation and during transient analysis, the goal was to determine the temperature after 10 minutes and the time to reach steady state.

## Assumptions

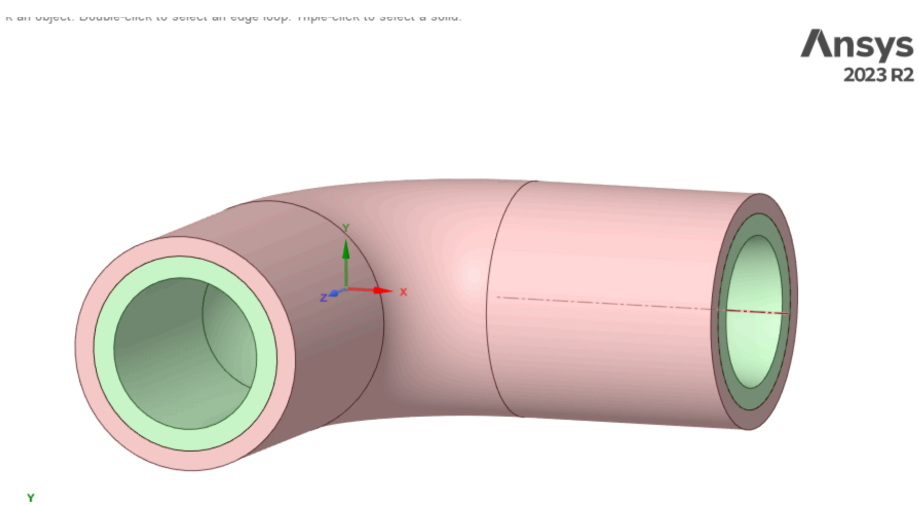
For all situations below, it is assumed that radiation can be ignored, and contact resistance between metal and insulation is negligible (for physical modeling of insulation).

## Geometry

For Part A, a curved pipe was created in SpaceClaim with these dimensions:

- Metal Pipe: Inner diameter: 70 mm & outer diameter: 90 mm
- Insulation: Inner diameter: 90 mm & outer diameter: 106, 108, and 110 mm

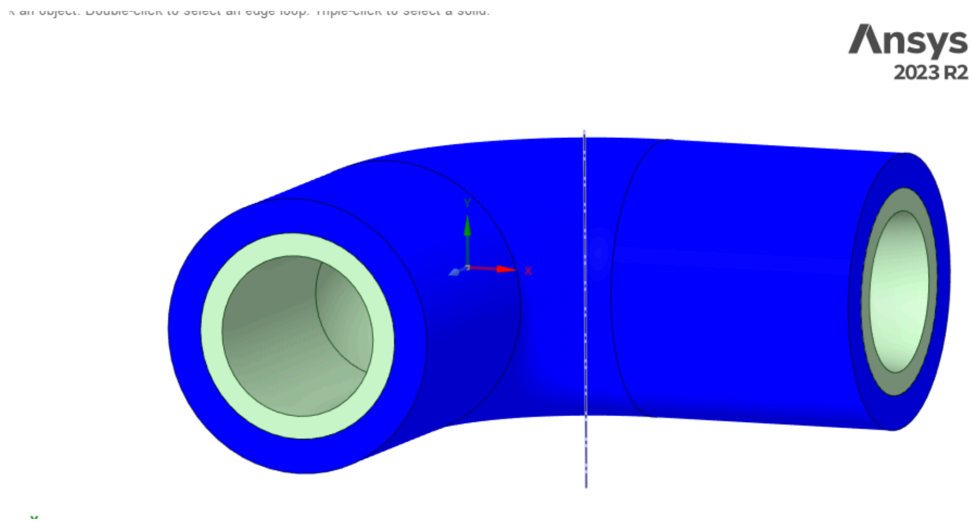
The resulting geometry is shown below (108mm insulation):




For Part B, a curved pipe was created in SpaceClaim with these dimensions:

- Metal Pipe: Inner diameter: 70 mm & outer diameter: 90 mm
- Insulation: Inner diameter: 90 mm & outer diameter: 120 mm

The resulting geometry is shown below:




## Material Data

The thermal properties of both of the cast iron and insulation are shown in the tables below:

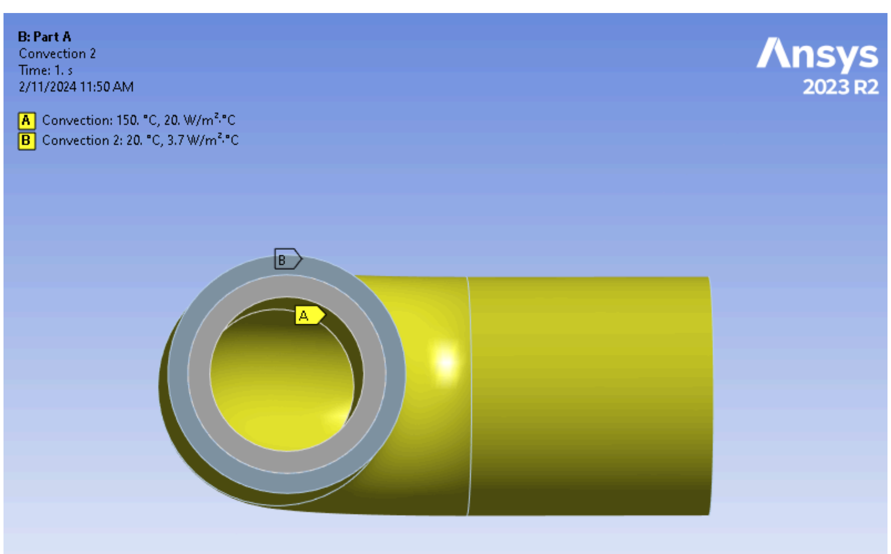
| | Density (kg/m$^3$) | Specific Heat (J/kg-C) | Thermal Conductivity (W/m-C) |
|---|---|---|---|
| Cast Iron | 7200 | 447 | See Table -> |
| Insulation | 2500 | 840 | 0.2 |

| Thermal Conductivity | |
|---|---|
| $T$ ( C) | $K$ (W/m-C) |
| 20 | 51.6 |
| 100 | 50.8 |
| 200 | 49.8 |
| 300 | 48.8 |
| 400 | 47.8 |
| 500 | 46.8 |

## Boundary Conditions

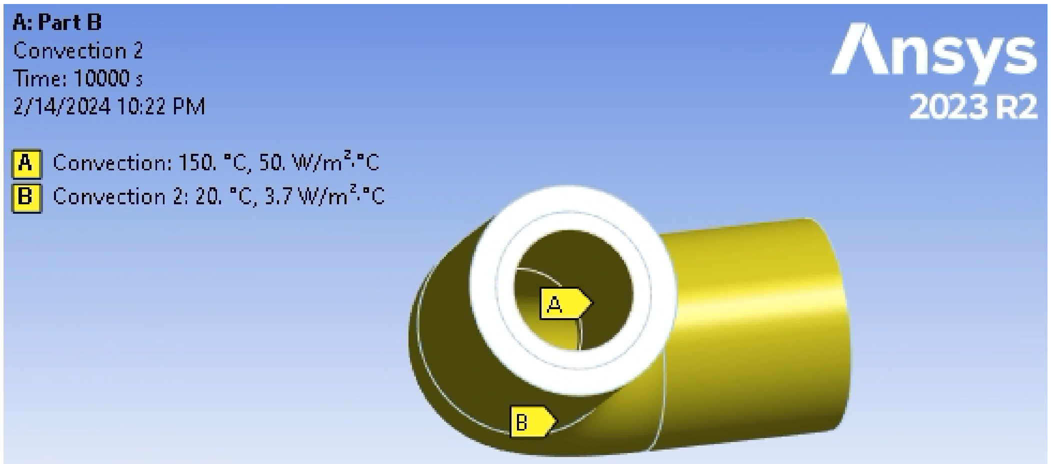
For Part A:

- Convection condition of 20 deg C, 3.7 W/m$^2$-C at outside faces of the pipe
- Convection condition of 150 deg C, 20. W/m$^2$-C at inside faces of the pipe
- Adiabatic condition at end faces of pipe (default)



For Part A:

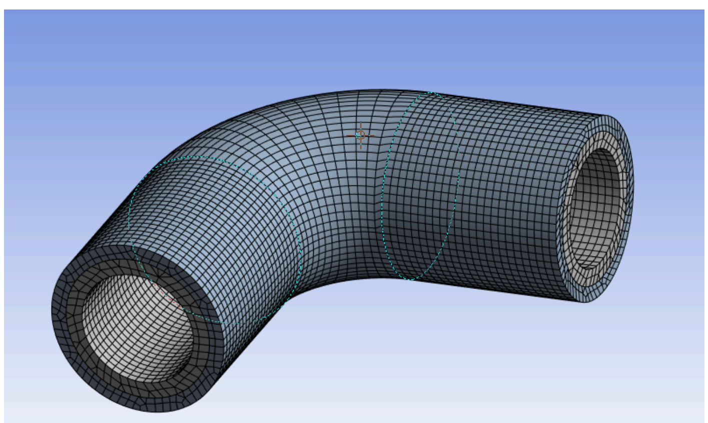
- Convection condition of 20 deg C, 3.7 W/m$^2$-C at outside faces of the pipe
- Convection shock condition of 150 deg C, 50. W/m$^2$-C at inside faces of the pipe
  - Set to 150 deg C at t = 1 sec for shock condition
- Adiabatic condition at end faces of pipe (default)




## Mesh and Solution Setup

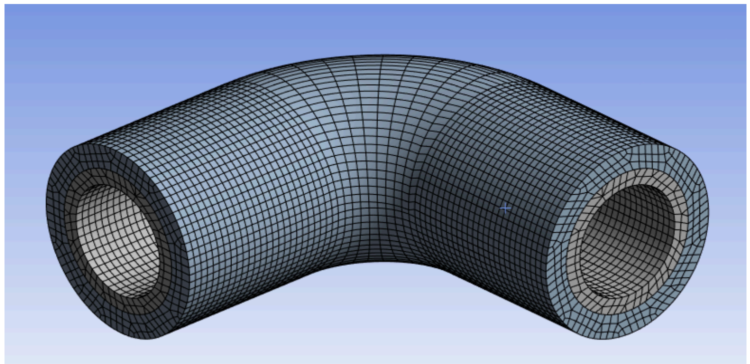
For Part A, two meshes were generated for Part A with default settings and element sizes of default and 5mm. There were small observed differences between results between 5mm and default as shown below, thereby indicating that the mesh is converged. 5mm shown below.

| | Nodes | Elements | Temperature (°C) | |
|---|---|---|---|---|
| | | | Minimum | Maximum |
| **Solution 1:** 02/11/2024 11:42 AM | 13,631 | 7,445 | 107.8 | 110.16 |
| **Solution 2:** 02/11/2024 11:45 AM | 79,399 | 36,166 | 107.81 | 110.17 |



Three meshes were generated for Part B with default settings and element sizes of 5mm, 20mm, and 100mm respectively. There were small observed differences between results, thereby indicating that the mesh is converged. 5mm shown on the next page.

| | Nodes | Elements | Temperature (°C) | |
|---|---|---|---|---|
| | | | Minimum | Maximum |
| **Solution 1:** 02/11/2024 12:27 PM | 4,245 | 2,340 | 26.147 | 27.875 |
| **Solution 2:** 02/11/2024 12:27 PM | 7,182 | 4,096 | 25.793 | 27.914 |
| **Solution 3:** 02/11/2024 12:30 PM | 96,052 | 40,348 | 26.348 | 28.131 |



For part A, a reaction probe was created to measure heat lost through the convection at the outermost surface of the insulation (3 faces). For both parts, max temperature was measured for the outer surface of the insulation (3 faces). Default conditions were otherwise used. For Part B, the following time step settings were used:

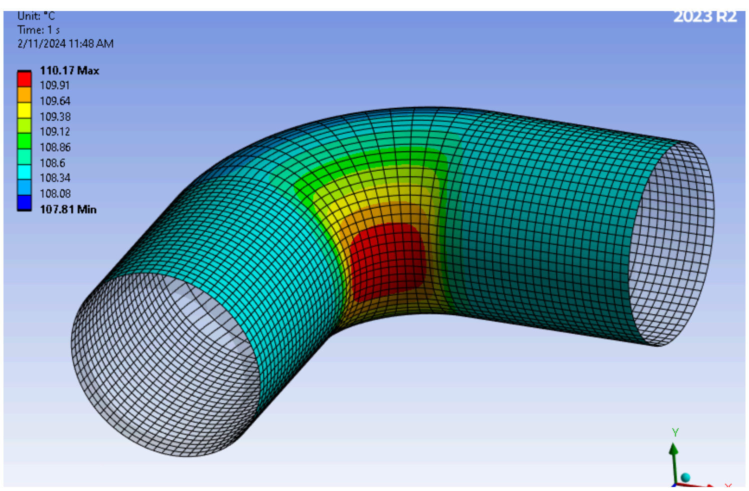
Details of "Analysis Settings"

| Step Controls | |
|---|---|
| Number Of Steps | 1. |
| Current Step Number | 1. |
| Step End Time | 600. s |
| Auto Time Stepping | Off |
| Define By | Time |
| Time Step | 5. s |
| Time Integration | On |

| Step Controls | |
|---|---|
| Number Of Steps | 1. |
| Current Step Number | 1. |
| Step End Time | 10000 s |
| Auto Time Stepping | Off |
| Define By | Time |
| Time Step | 50. s |
| Time Integration | On |

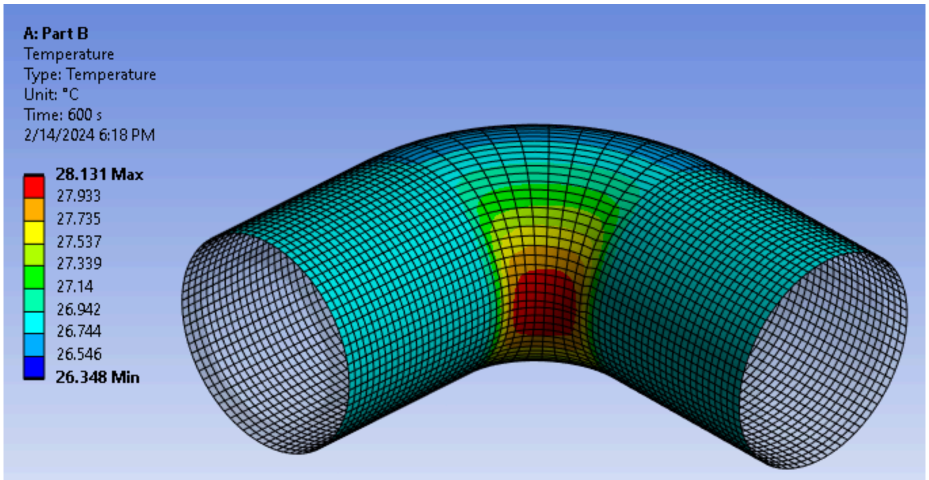
## Results

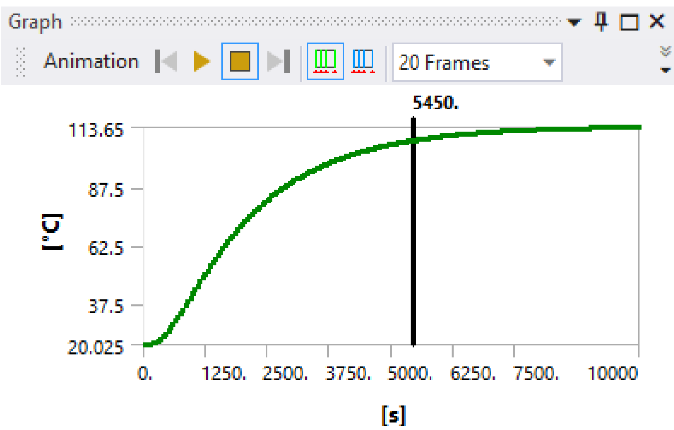
Part A:




The outside surface of the insulation had a max temperature of 110 deg C and the critical radius was determined to be 54mm using r = k/h. This result was empirically verified by using radii of 53mm and 55mm to verify that the heat loss was indeed lower. Heat loss at 54mm was -40.153 W while it was -40.149 W at 53mm and -40.133 W at 55mm, thereby confirming 54mm is indeed the correct critical radius.

For Part B:




Tabular Data

| | Time [s] | Minimum [°C] | Maximum [°C] | Average [°C] |
|---|---|---|---|---|
| 109 | 5450. | 101.68 | 107.9 | 103.37 |
| 110 | 5500. | 101.86 | 108.07 | 103.55 |
| 111 | 5550. | 102.04 | 108.23 | 103.72 |
| 112 | 5600. | 102.21 | 108.39 | 103.89 |
| 113 | 5650. | 102.38 | 108.55 | 104.06 |
| 114 | 5700. | 102.54 | 108.7 | 104.21 |
| 115 | 5750. | 102.7 | 108.85 | 104.37 |
| 116 | 5800. | 102.86 | 108.99 | 104.52 |
| 117 | 5850. | 103.01 | 109.13 | 104.67 |
| 118 | 5900. | 103.15 | 109.27 | 104.81 |
| 119 | 5950. | 103.3 | 109.4 | 104.95 |
| 120 | 6000. | 103.43 | 109.53 | 105.08 |

The outside surface of the metal pipe had a max temperature of 28 deg C at 10 mins and steady state (95% of 113.65 = 107.9) was determined to be at 91 minutes.

## Conclusion

Overall, the results of the simulations make sense given the conditions used. Steady state and transient analyses were conducted under different insulation conditions. Max temperatures were determined at steady state and transient analysis and critical radius was determined and verified empirically.