24-650 Applied Finite Element Analysis

Assignment 2

submitted by

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Objective

The goal of this assignment is to explore the steady-state thermal critical radius of the insulation. The main object is a cast iron pipe with a 90-degree bend. The inside and outside diameters are 70 mm and 90 mm, accordingly.

Assumptions and Conditions

1) Heat transfer is steady-state in part A, and is transient in part B.
2) The pipe ends are adiabatic.
3) No radiation.
4) The thermal conductivity, density and specific heat of the pipe is given below:

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

Density: 7200 kg/m^3
Specific Heat = 447 J/kg-C

Model and Geometry

The cast iron pipe (see in Fig.1) has inside and outside diameters are 70 mm and 90 mm, accordingly. Also heat insulation is applied to the outer surface of the pipe (see in Fig.2). For the mesh size, 0.01m element size has been used under the balance of solution accuracy and computation time. From the result section below, one can see that the contour edges of different colors are smooth without sharp curves.

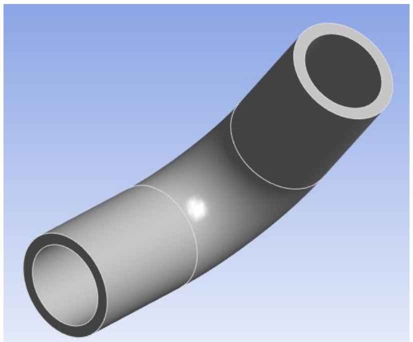


Figure 1. The curved pipe

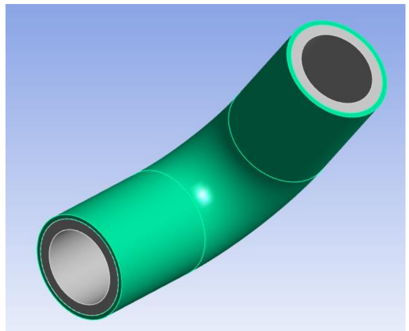


Figure 2. The pipe with foam insulation (green)

Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	Mechanical
Element Order	Program Controlled
Element Size	1.e-002 m
Sizing	
Use Adaptive Sizing	Yes
Resolution	Default (2)
Mesh Defeaturing	Yes
Defeature Size	Default
Transition	Fast
Span Angle Center	Coarse
Initial Size Seed	Assembly
Bounding Box Diagonal	0.35798 m
Average Surface Area	2.3312e-002 m²
Minimum Edge Length	0.21991 m

Mesh Settings

Boundary Conditions (Part A)

The pipe is carrying steam at 150 °C, with an outside temperature of 20 °C.

We assume that the pipe ends are adiabatic.

The inside surface has a convention coefficient of 20 W/m^2 -C, with an outside surface convention coefficient of 3.7 W/m^2 -C.

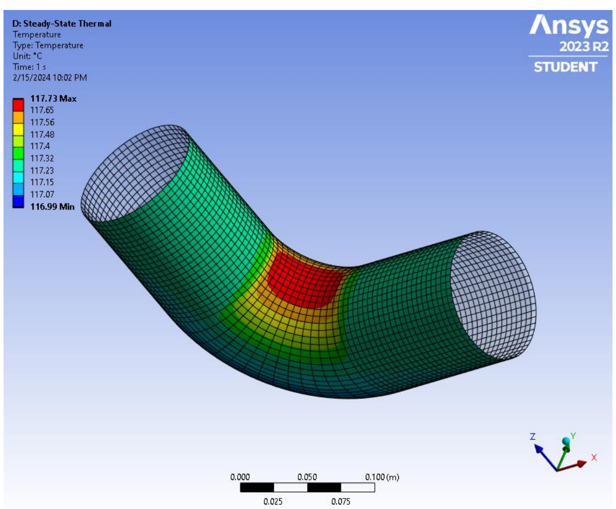
Definition	
Type	Convection
Film Coefficient	20. W/m²·°C (step applied)
Ambient Temperature	150. °C (ramped)

Convection for inner surface

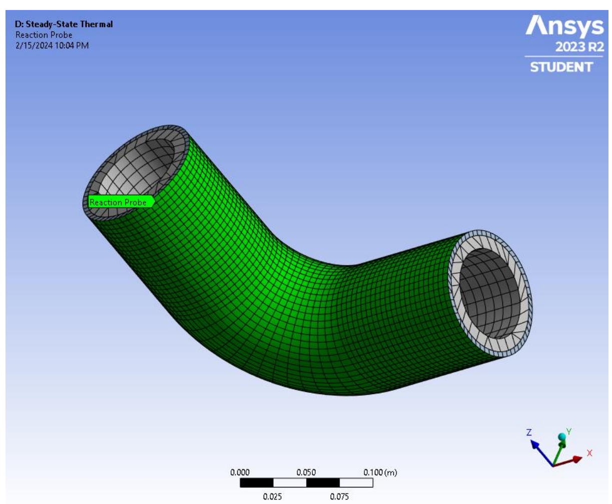
Definition	
Type	Convection
Film Coefficient	3.7 W/m²·°C (step applied)
Ambient Temperature	20. °C (ramped)

Convection for outer surface

Results (Part A)



Result example, outside temp (°C)



Result example, heat loss (W)

Insulation thickness (mm)	Max Outside Temperature (C^o)	Heat Loss (W)
0	125.09	-39.67
2	121.25	-38.88
4	117.73	-40.02
6	114.52	-40.11
8	**111.60**	**-40.15**
10	**108.94**	**-40.15**
12	100.03	-36.23

From the table above, one can find that the heat loss reaches the maximum at between 8-10mm thickness, so the conclusion is the critical thickness happens in between 8-10mm thickness of insulation, most likely around **9mm** thickness.

Boundary Conditions (Part B)

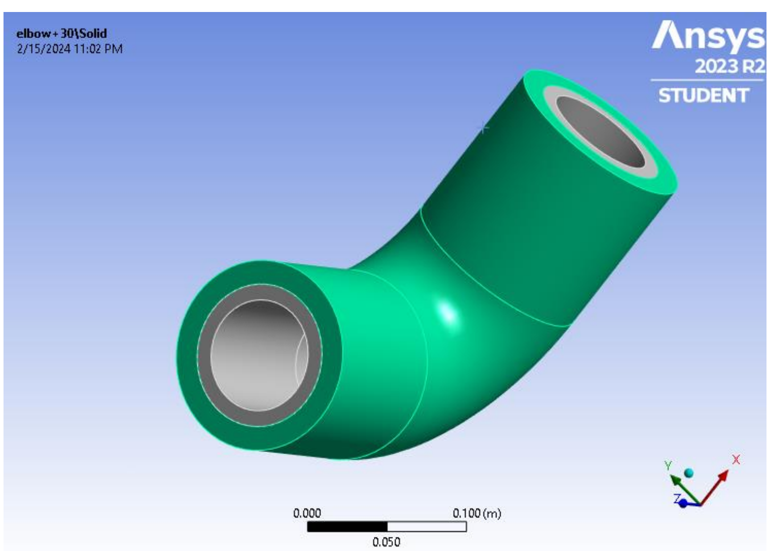
The initial temperature of the entire structure is uniform at 20°C.

The inner surface of the pipe experiences a sudden convection shock, with rapidly moving steam at 150°C and a convection coefficient of 50 W/m2-C.

The outer convection coefficient is 3.7 W/m2-C, and the highest external temperature is 20°C.

It is assumed that the pipe ends are adiabatic.

The insulation has density and specific heat properties of 2500 kg/m3 and 840 J/kg-C, respectively.



Pipe with 15-mm thick insulation.

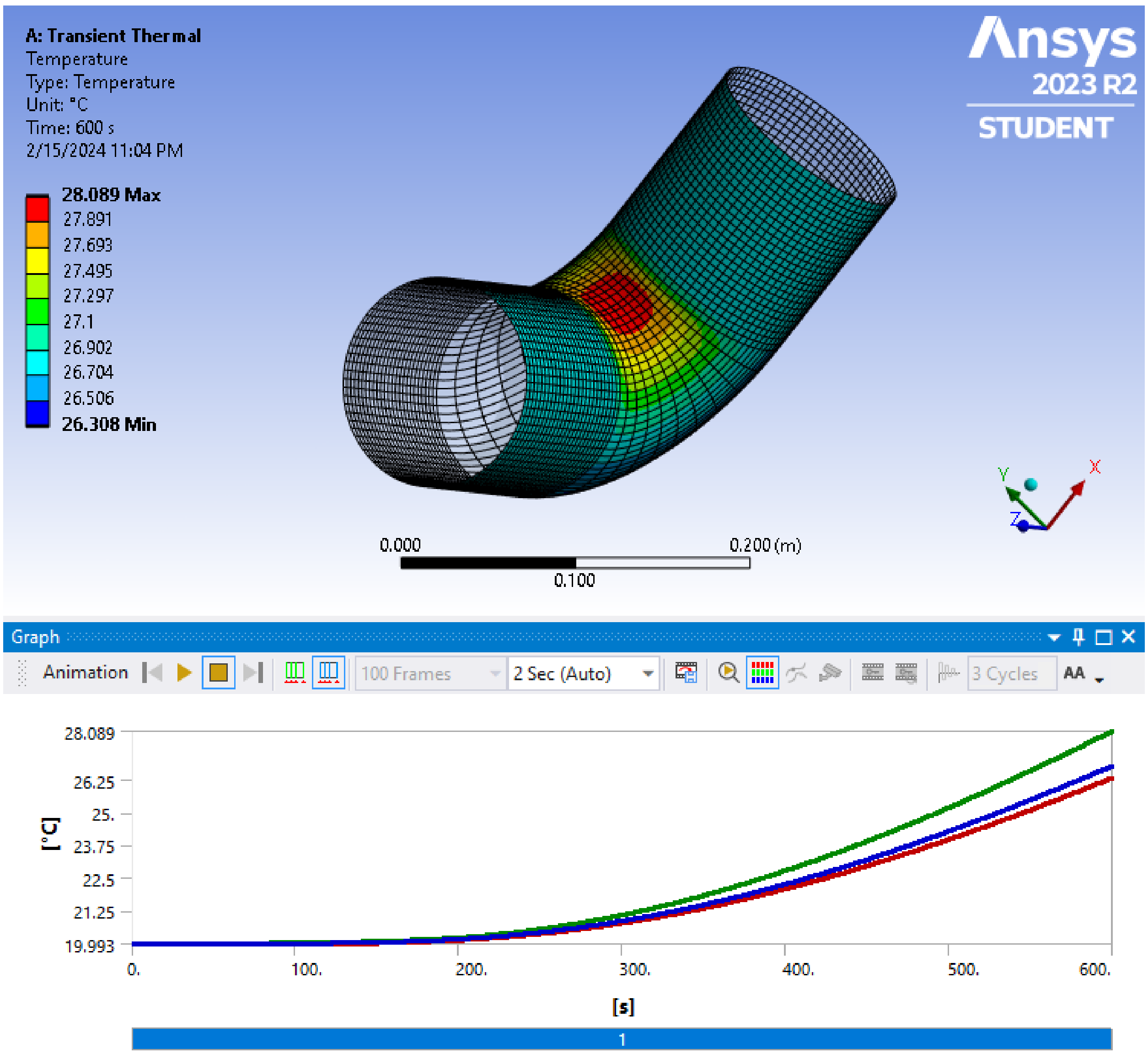
Definition	
Type	Convection
Film Coefficient	50. W/m²·°C (step applied)
Ambient Temperature	150. °C (step applied)
Convection Matrix	Program Controlled
Suppressed	No

Convection for inner surface

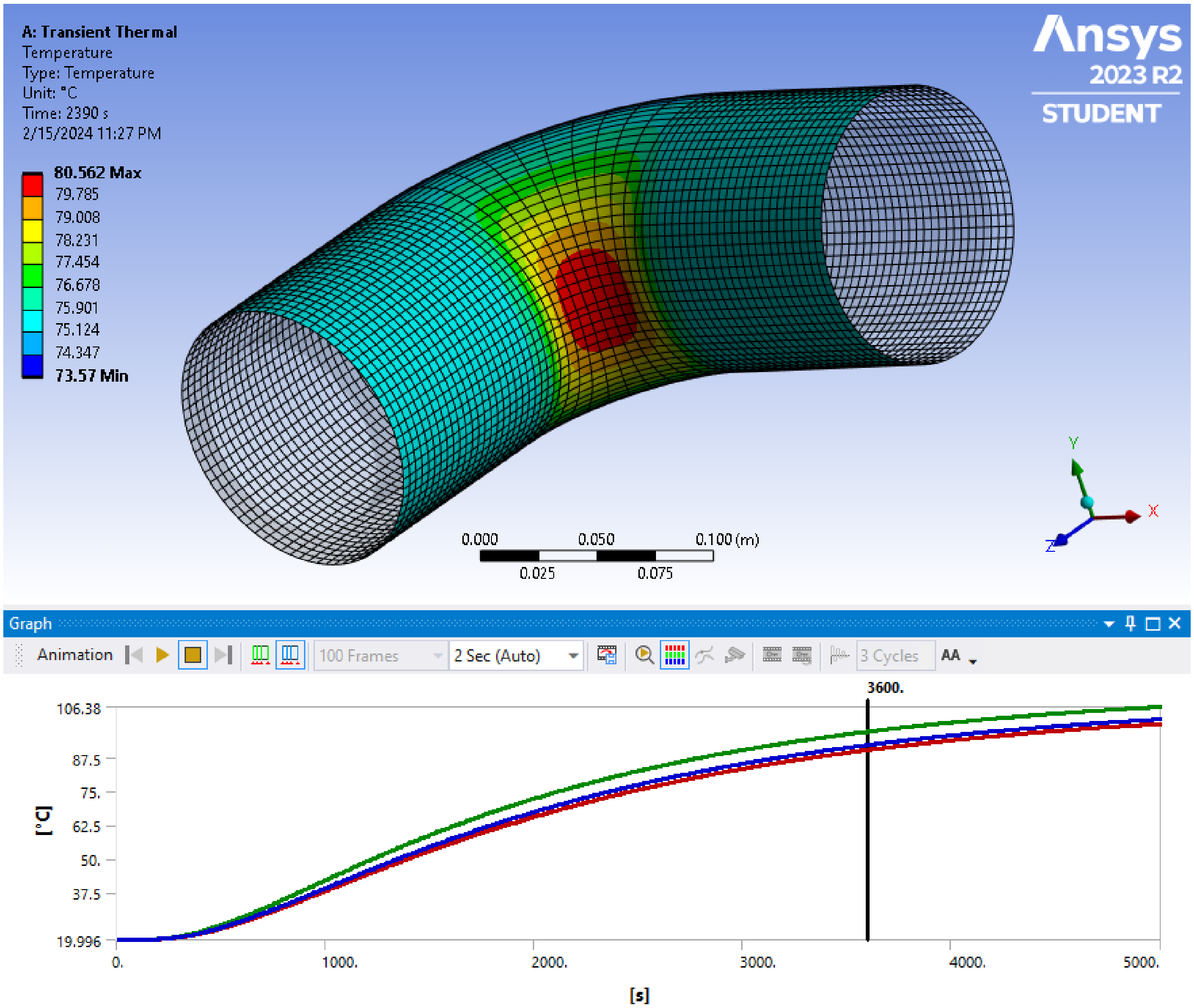
Definition	
Type	Convection
Film Coefficient	3.7 W/m²·°C (step applied)
Ambient Temperature	20. °C (step applied)
Convection Matrix	Program Controlled
Suppressed	No

Convection for inner surface

Results (Part B)



From above, the maximum temperature at 10 minutes is **28°C.**



From the figure above, the maximum temperature to achieve the steady-state outside temperature (103°C) is about **3600s**, which is about **an hour**.

Conclusion

From this assignment, one can find that when doing computation-extensive task, such as long-time transient thermal analysis, the mesh density and time step can be traded off if the computation time is long. The increasing of timestep and decreasing of mesh element size significantly reduced the computing time.