MOOSE Project Report

Jess Williams

NE 533

1. Part 1

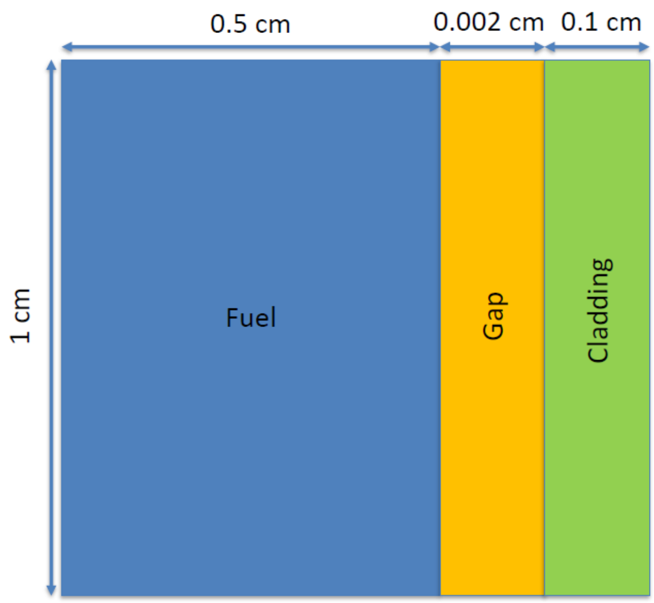

Figure 1.1: Fuel Pin Geometry and Dimensions

The goal of Part 1 of this project was to evaluate the temperature profile of a 1D fuel pin at steady state and as a function of time. Figure 1.1 illustrates the geometry and dimensions of the fuel pin examined in the first part of this study. Although this is a 1D problem, the geometry was set up in 2D RZ in the MOOSE input. A constant thermal conductivity was assumed for all materials as shown in Table 1.1 based on the assumption that the fuel is uranium dioxide and the cladding is zirconium, and the gap is helium, and the properties are given as listed in Lecture 4 [1].

Table 1.1: Material Properties

Material	Thermal Conductivity ($W/(cm \cdot K)$)	Specific Heat ($J/g \cdot K$)
Fuel	0.03	0.33
Gap	0.0026	5.193
Cladding	0.17	0.35

The temperature profile was solved for the steady state with the linear heat rate LHR $= 150\,\mathrm{W/cm^2}$ and the outer cladding temperature set to 500 K. The analytical solution was calculated using Equation 1.1. The MOOSE-calculated and analytic results are shown in Table 1.2. The MOOSE results were significantly higher than the analytical results, suggesting that there may have been an issue with setting up the problem, the constants used, or the mesh.

$$T_0 - T_{fuel} = \frac{LHR}{4\pi k} \tag{1.1}$$

$$T_{fuel} - T_{CI} = \frac{LHR}{2\pi R_{fuel} h_{gap}}; h_{gap} = \frac{k_{gap}}{t_{gap}}$$

$$T_{CI} - T_{CO} = \frac{LHR \cdot t_{clad}}{2\pi R_{fuel} k_{clad}}$$

Table 1.2: Steady State Temperature Profile

	Temperature (K)	
Location	MOOSE	Analytical
Fuel Centerline	1226.81	962.70
Outer Fuel	601.81	564.81
Inner Clad	544.12	528.09
Outer Clad	500	500

Next, MOOSE's transient capabilities were used to solve for the centerline temperature as a function of time where the transient is an increase in LHR over time. The LHR as a function of time is given by Equation 1.2. The transient was modeled for 100 s with time steps of 10 s each.

$$LHR = 150 \times (1 - e^{-0.05t}) + 150 \tag{1.2}$$

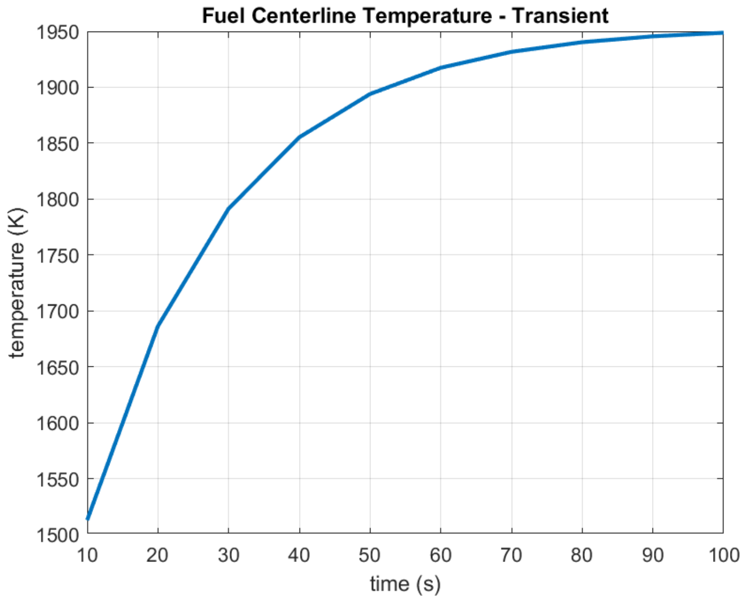

Figure 1.2: Transient Fuel Centerline Temperature

Figure 1.2 shows the fuel centerline temperature as a function of time as the LHR increases over time. As the LHR increases over time, so does the fuel centerline temperature. The rate at which the temperature increased decreased with each time step and approached 1950 K asymptotically. The rate of temperature increase likely decreases because the LHR does not change as drastically with increasing time.

2. Part 2

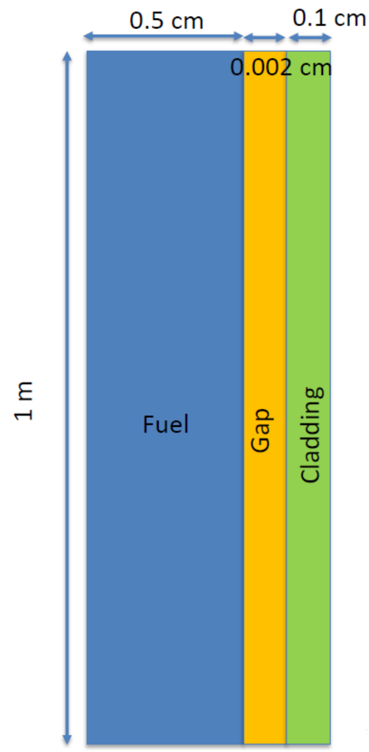

Figure 2.1: Fuel Pin Geometry and Dimensions

Like Part 1, the goal of Part 2 of this project was to solve the temperature profile at steady state and solve for the centerline temperature as a function of time given a transient in which the LHR varies as a function of time. Figure 2.1 illustrates the geometry of the fuel pin used in this part of the study. The same thermal conductivities used in Part 1 and listed in Table 1.1 were used for this problem.

The axial coolant temperature was utilized. The assumed properties are given in Table 2.1 assuming that the coolant is light water. Axial LHR was also utilized. The axial LHR and axial coolant temperatures are given in Equations 2.1 and 2.2, respectively, and $\mathrm{LHR}^0 = 150\ \mathrm{W/cm}$.

Table 2.1: Coolant Properties

Property	Value
Inlet Temperature	400 K
Flow Rate	250 g/s-rod [1]
Heat Capacity	4.2 J/g-K [1]

$$LHR\left(\frac{z}{Z_0}\right) = LHR^0 \cos\left[\frac{\pi}{2\gamma}\left(\frac{z}{Z_0} - 1\right)\right] = LHR^0 F\left(\frac{z}{Z_0}\right) \tag{2.1}$$

$$T_{cool} - T_{cool}^{in} = \frac{1}{1.2} \cdot \frac{(Z_0 \times LHR^0)}{\dot{m}C_{PW}}\left\{\sin(1.2) + \sin\left[1.2\left(\frac{z}{Z_0} - 1\right)\right]\right\} \tag{2.2}$$

The temperature profile was solved at $z = [0.25, 0.5, 1]$ at steady state as given in Table 2.2.

Table 2.2: Temperature Profile

	Temperature		
Location	$z = 0.25$	$z = 0.5$	$z = 1$
Coolant			
Outer Cladding			
Inner Cladding			
Outer Fuel			
Fuel Centerline			

Next, the centerline temperature was solved for as a function of time where LHR^0 increases as a function of time as given by Equation 2.3. The transient was evaluated for 100 s and at $z = [0.25, 0.5, 1]$.

$$LHR^0(t) = LHR^0(1 - e^{-0.1t}) + 50 \tag{1.2}$$

Next, the location of the peak centerline temperature at steady-state and at the end of the transient was determined.

3. Part 3

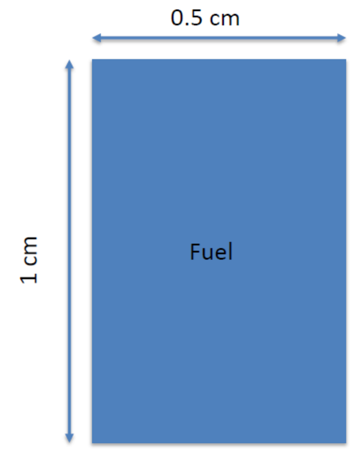

Figure 3.1: Fuel Dimensions

The objective in Part 3 of this project was to evaluate the stresses on fuel due to thermal expansion given a uniform heat generation rate $\mathrm{LHR} = 175\ \mathrm{W/cm}$. MOOSE's tensor mechanics module was utilized in addition to the heat conduction module used in the previous parts to evaluate the stresses on the fuel.

First, a constant fuel surface temperature and constant thermal conductivity were assumed. The fuel surface temperature was assumed to be 550K and the thermal conductivity was assumed to be $0.03\ \mathrm{W/cm \cdot s}$. The thermal expansion was assumed to be 1.0×10^{-5} [1], the Young's Modulus was assumed to be 200 GPa [2], and the Poisson's Ratio was assumed to be 0.345 [2].

Next, the fuel surface temperature was kept constant, but the thermal conductivity was assumed to be temperature dependent. The thermal conductivity of the fuel is given by Equation 3.1 [3].

$$k\left[\frac{W}{m \cdot K}\right] = \frac{100}{7.5408 + 17.692\tau + 3.6142\tau^2} + \frac{6400}{\tau^{\frac{5}{2}}} \exp\left(-\frac{16.35}{\tau}\right) \tag{3.1}$$

$$\tau = \frac{T}{1000}$$

References

[1] Beeler, Benjamin. "Analytical Solve of Heat Conduction," Nuclear Fuel Performance, Lecture 4, 2022.

[2] Beeler, Benjamin. "Mechanics," Nuclear Fuel Performance, Lecture 5, 2022.

[3] "Thermal Conductivity of Uranium Dioxide," https://www.nuclear-power.com/nuclear-engineering/heat-transfer/thermal-conduction/thermal-conductivity/thermal-conductivity-of-uranium-dioxide/.