North Carolina State University

NE 533

Nuclear Fuel Performance

MOOSE Project: Part I

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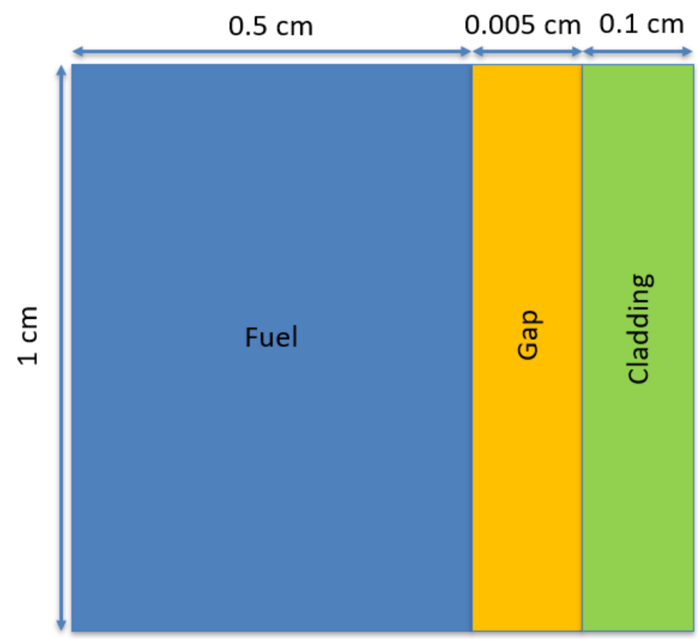
Problem Statement

- Fuel pellet dimensions listed
- This is a 1-D problem, but geometry to be set up in 2-D RZ
- Assume reasonable values for material properties
- Outer cladding temperature: 550 K
- Solve temperature profile for:
- Steady-state: LHR = 350 W/cm^2
- Compare against analytical solution.
- Solve for centerline temperature vs time Transient: LHR = 250*EXP(-((t-20)^2)/10)+150 for up to t=100

Use both a constant k and a temperature-dependent k



Methodology

We know, the heat conduction governing equation for axisymmetric cylindrical fuel rod:

$$\frac{1}{r}.\frac{\partial}{\partial r}\left(rk\frac{\partial T}{\partial r}\right) - q''' = \rho C_p \frac{\partial T}{\partial t}$$

Where, k = Thermal conductivity

r = Radius

ρ = density

C_p = specific heat

t = time

T = Temperature

q''' = volumetric heat generation

For steady state, the time derivative is 0.

$$\frac{1}{r}.\frac{\partial}{\partial r}\left(rk\frac{\partial T}{\partial r}\right) - q''' = 0$$

Assumptions

1. Heat is only generated in the fuel.
2. In steady state, the heat generation is constant.
3. All material properties remain unchanged over time and temperatures.
4. There is good thermal contact between each block.

Material Properties

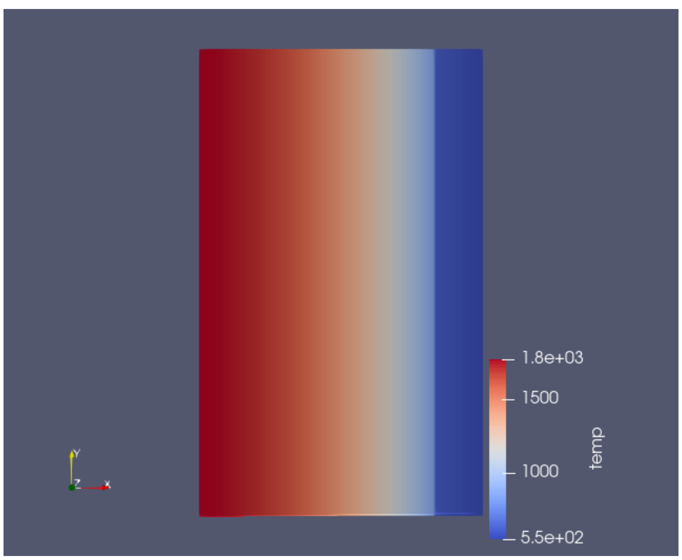
Section	Thermal Conductivity (W/cm-k)
Fuel	0.03
Gap	0.0026
Cladding	0.17

Boundary Conditions

At r = 0, $\frac{\partial T}{\partial r} = 0$; at r = R, T = 550 K (Steady state)

At t = 0, T = 550 K; time step, dt = 1 total = 100 time steps, up to t = 84.25s (Transient Analysis)

Details on Steady State Problem



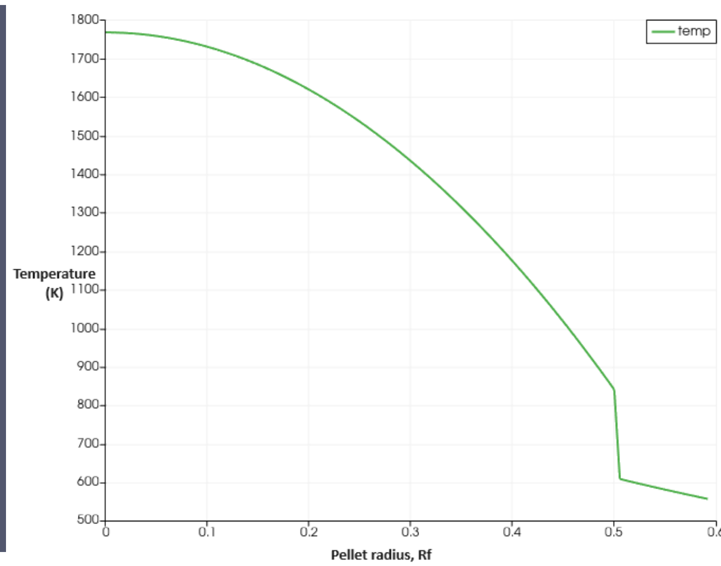


Figure 1. Colored contour plotting of the geometry (left) and temperature vs pellet radius plotting (right)

Point	Analytical Result (K)	Simulated Result (K)	Deviation (%)
Fuel Centerline	1758.18	1768.16	**0.568**
Fuel Surface	829.78	811.345	2.22
Cladding Inner Surface	615.53	609.941	0.91

Details on Transient Problem

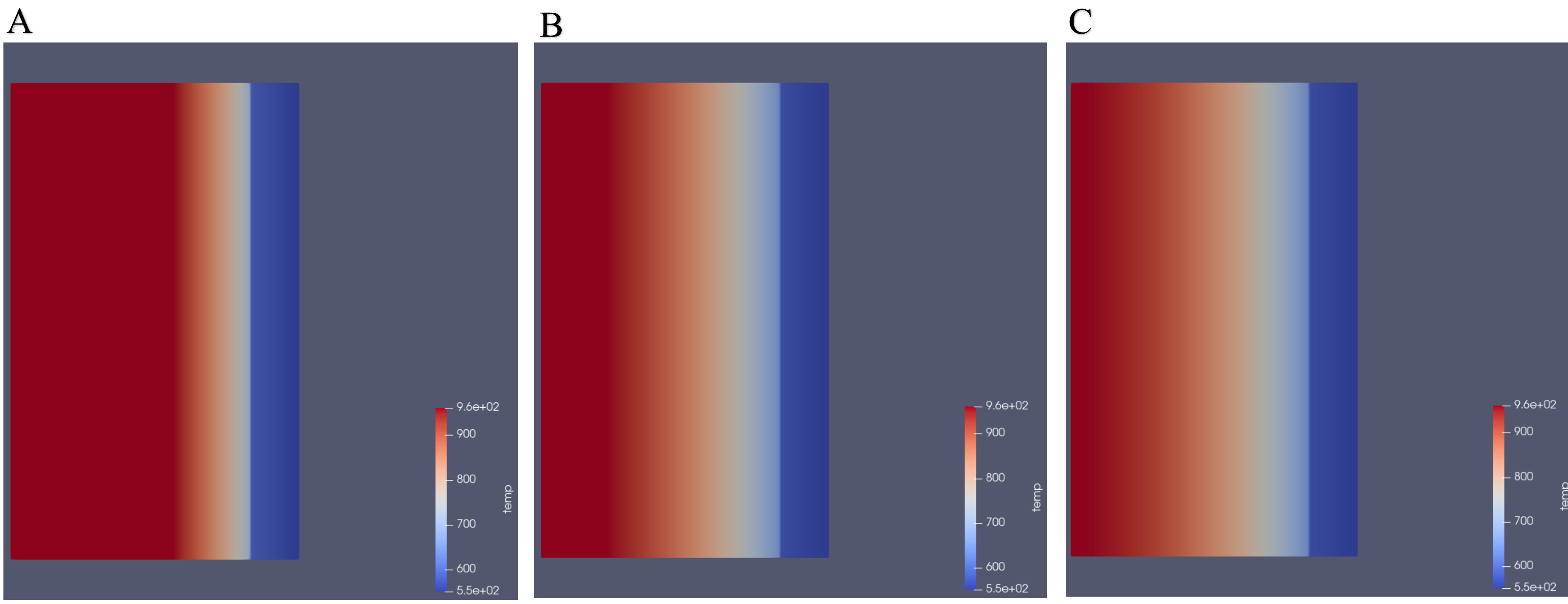


Figure 2. Colored contour transient plotting of the geometry taken at (A) 20s, (B) 40s and (C) 84.25s

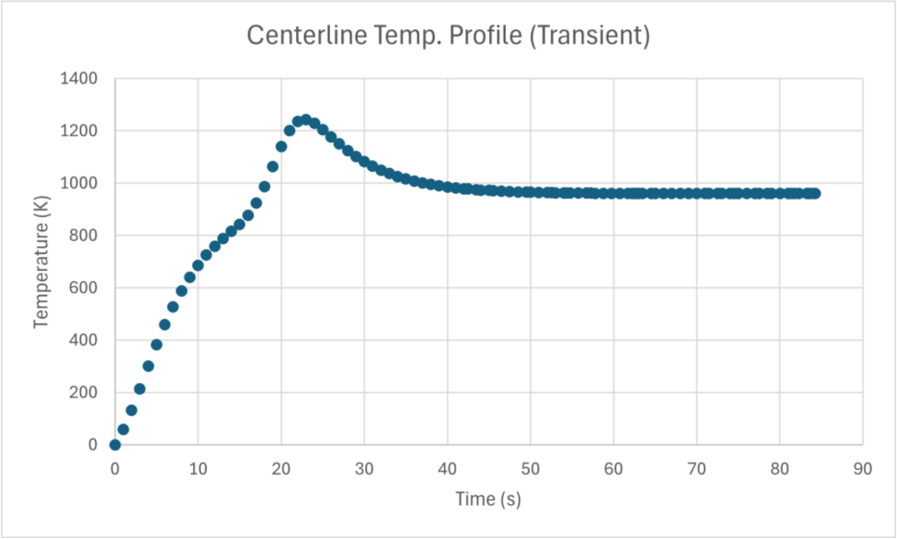


Figure 3. Temperature profile for the system. The system turns into steady state from transient at around 84s.

- There is a sudden increase in centerline temperature; initial temperature (550K) was less than the steady state temperature (960K).
- Maximum centerline temperature is 1242.33K which is far below the UO_2 melting temperature (3138K).
- At 61.75s, the system reaches a steady state temperature (~ 960K).
- The steady state had been reached at around 61.75s and then it was extended to 84.25s to display the steady state region of the curve.

Conclusion

- From numerical method, reliable data have been found. Deviation is around 0.5% while calculating the centerline temperature.
- A linear temperature profile is found at cladding and gap region, whereas parabolic profile can be seen in fuel region (Figure 1).
- After about 1 minute, the transient system becomes steady state. The time required for the system to become steady is strongly dependent on thermal diffusivity.
- By modifying geometry, this method can be implemented for 2D case also.