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NE533 Nuclear Fuel Performance

1 March 2024

MOOSE Project Part 1 Writeup

In Part 1, we supposed to do four sets problems: (1) Steady state thermal source with constant thermal conductivity, K, (2) Transient state thermal source with constant K, (3) Steady state thermal source with temperature dependent K, and (4) Transient state thermal source with temperature dependent K.

1. **The deliverables from Part 1**:

For the problem (1), we can solve the temperature profile by the calculation processes below.

①

(1) As given, Steady state (With constant k), $LHR = 350\ W/cm^2$, $T_{CO} = 550\ K$

$R_f = R_{fuel} = 0.5\ cm$, $t_{gap} = 0.005\ cm$ ($= t_g$), $t_{cladding} = 0.1\ cm$ ($= t_c$)

Take constant k, $\begin{cases} K_{fuel}\,(UO_2) = 0.03\left[\frac{W}{cm\cdot K}\right] = k_f \\ k_{cladding}\,(Zr) = 0.17\left[\frac{W}{cm\cdot K}\right] = k_c \end{cases}$

$k_g = k_{gap}\,(He) = 16\times10^{-6}\times T^{0.79}$ take $k_{gap} = \text{const.} \doteq 2.556\times10^{-3}\left[\frac{W}{cm\cdot K}\right]$ @ $T = T_{CI} = 615.534\,K$

$$\Delta T_c = T_{CI} - T_{CO} = \frac{LHR}{2\pi R_f}\frac{t_c}{k_c} = \frac{350}{2\pi(0.5)}\frac{0.1}{0.17} \doteq 65.534\,K$$

$$T_{CI} = 550\ K + 65.534\,K = 615.534\,K$$

$$\Delta T_g = T_s - T_{CI} = \frac{LHR}{2\pi R_{fuel}}\times\frac{t_g}{k_g} = \frac{350}{2\times\pi\times0.5}\times\frac{0.005}{0.002556} = 217.935\ K$$

$$\Rightarrow T_s = 615.534 + 217.935 = 833.469$$

$$\Delta T_o = T_o - T_s = \frac{LHR}{4\pi k_{fuel}} = \frac{350}{4\pi\, 0.03} = 928.404$$

$$\Rightarrow T_o = 928.404 + 833.469 = 1761.873\quad K$$

By the MOOSE simulation, I obtained the temperature profiles results for problem (1) to (4), and the centerline temperature versus time data for problem (3) and (4). The temperature of the internal cladding, the surface of the fuel pellet, and the center of the fuel for problem (1) to (4) are listed in the Table 1.

Table 1. The temperature data for the internal cladding, the surface of the fuel pellet, and the center of the fuel

The unit of temperature: (K)	Steady State Constant k (analytical)	Steady State Constant k	Steady State Temperature-dependent k	Transient State Constant k	Transient State Temperature-dependent k
Centerline	1761.873	1772.35	1642.95	1073.88	925.253
surface of the fuel pellet	833.469	844.142	818.943	677.342	675.453
Inner surface of cladding	615.534	609.003	609.023	575.287	575.296

The visualized results of problem (1) to (4) are shown in Figure 1 to 4.

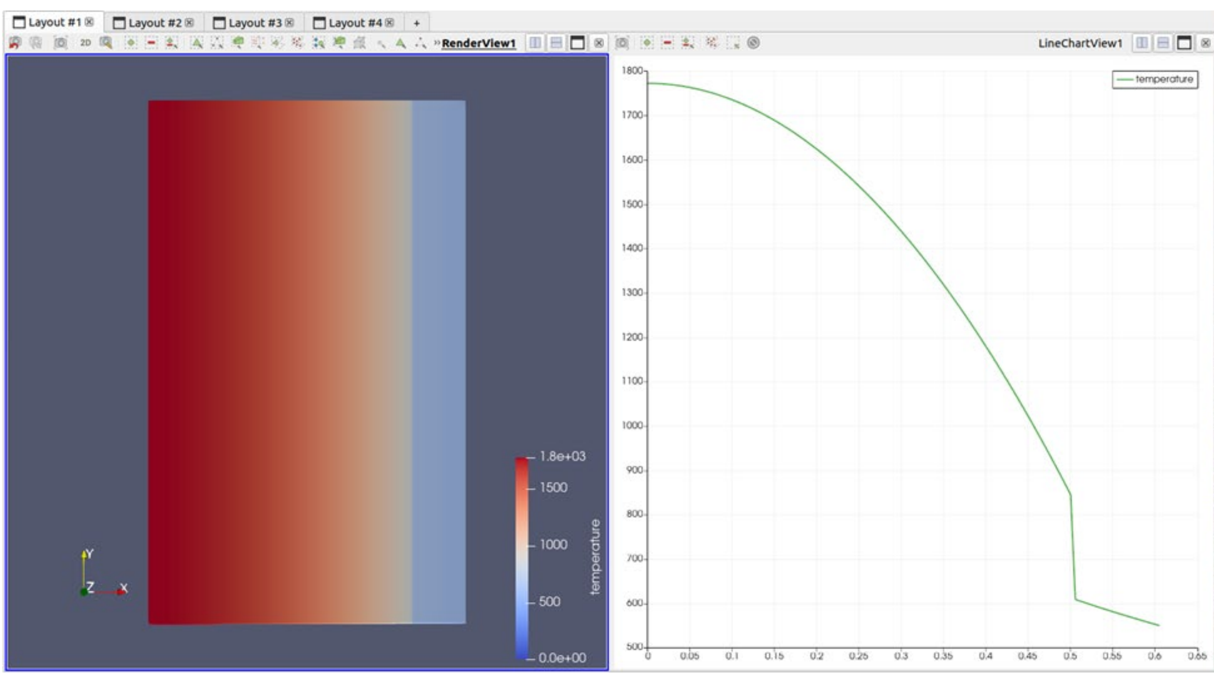

Figure 1. The temperature profile for Steady State Constant k (Problem (1))

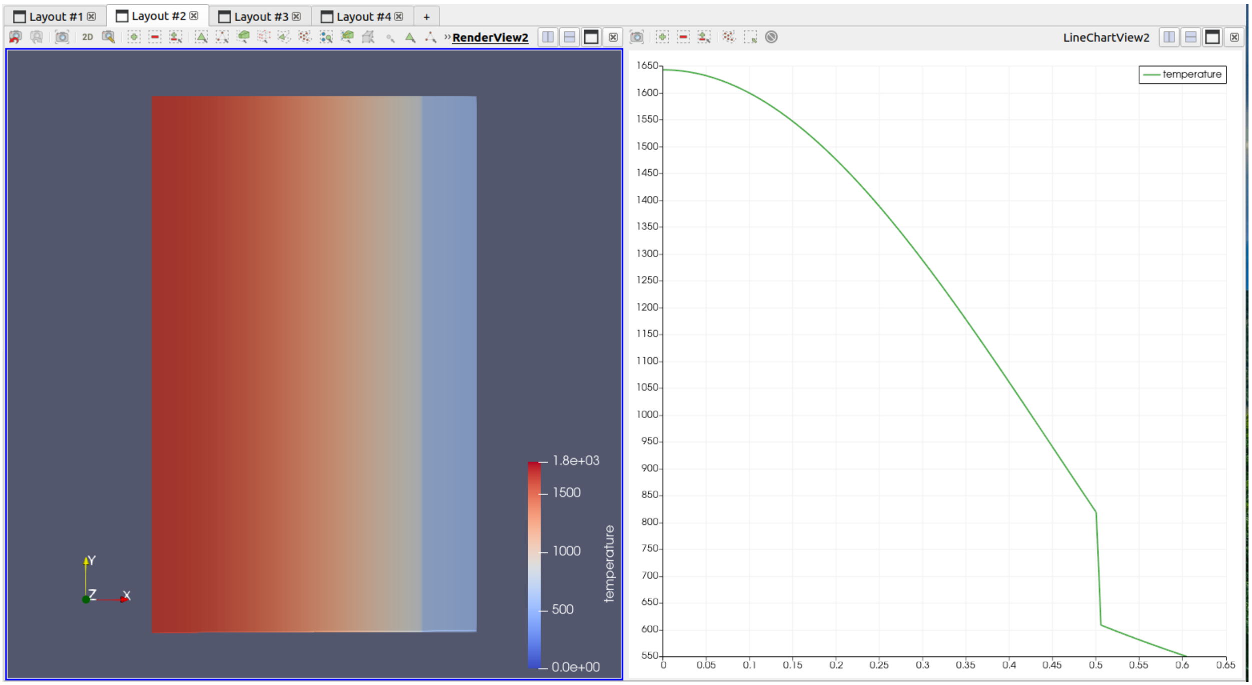

Figure 2. The temperature profile for Steady State Temperature-dependent k (Problem (2))

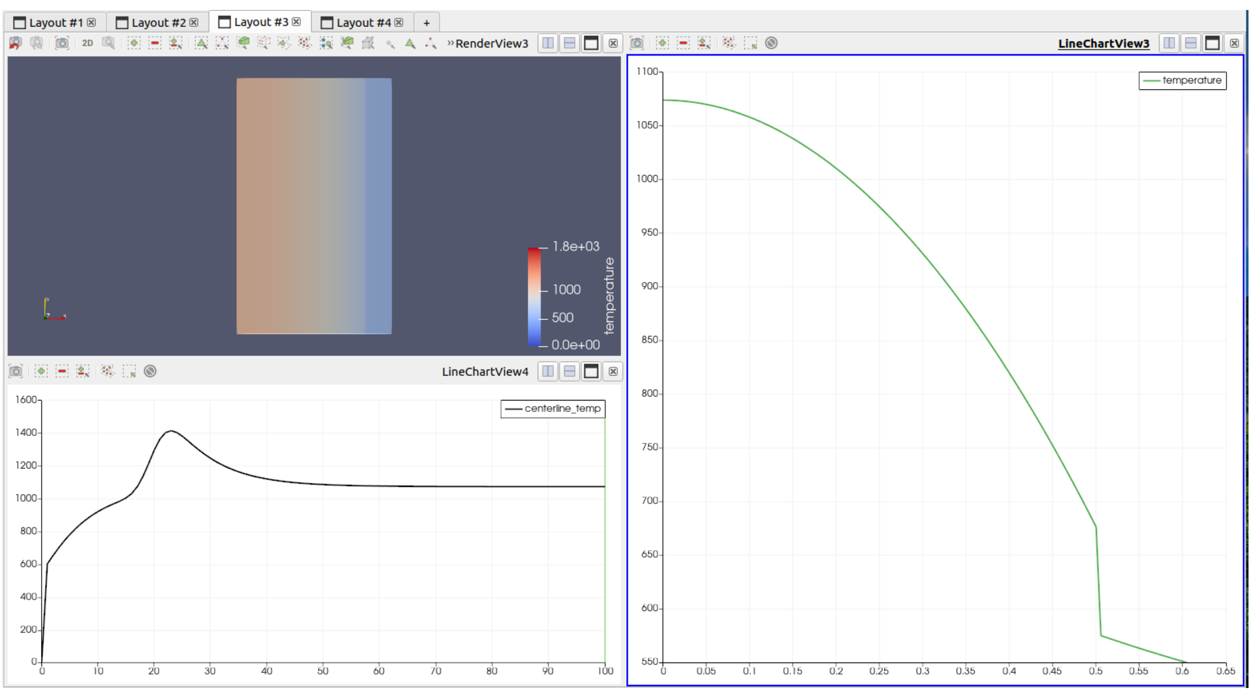

Figure 3. The temperature profile (Right) and the centerline temperature versus time (Lower Left) for Transient State Constant k (Problem (3))

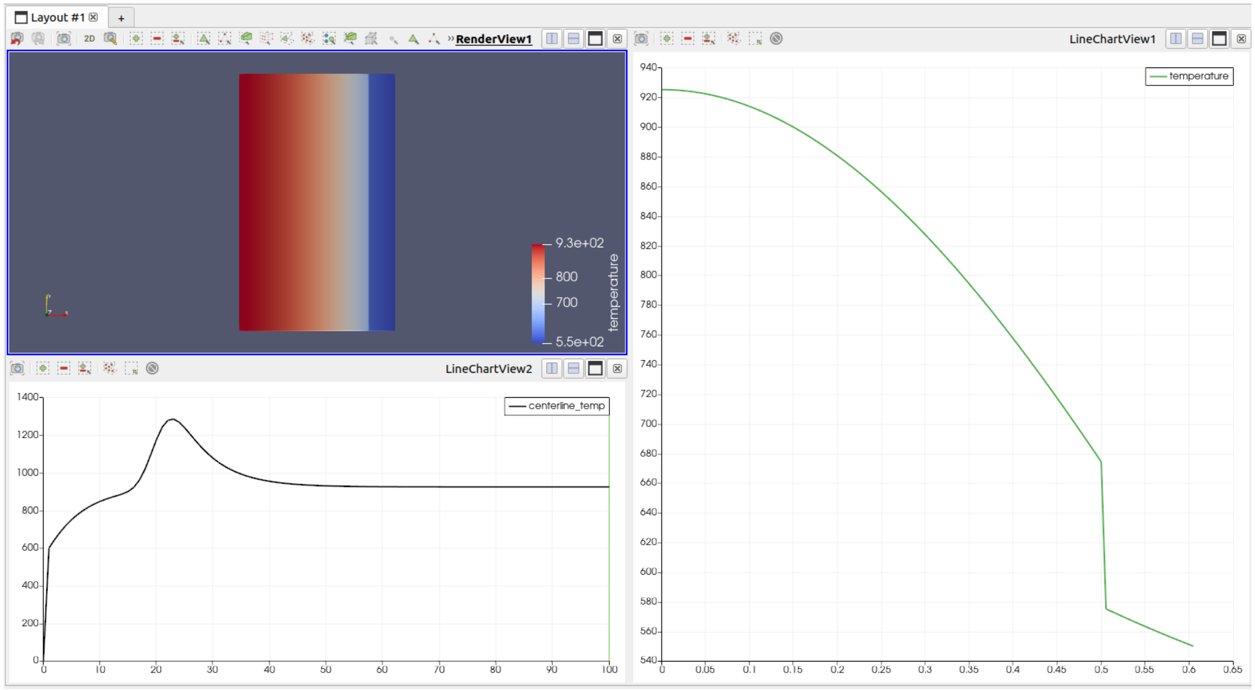

Figure 4. The temperature profile (Right) and the centerline temperature versus time (Lower Left) for Transient State Temperature-dependent k (Problem (4))

2. The details of the Part 1 project:

(1) Choices of materials and their parameters:

a. Fuel $\rightarrow UO_2$

In steady state (governing equation $0 = \nabla \cdot (\mathrm{k}\nabla\mathrm{T}) + \mathrm{Q}$), when we consider the constant k, the thermal conductivity is $0.03\ \frac{W}{cm*K}$ (From the lecture note); for the temperature dependent k, the thermal conductivity is $k_{ox} = \frac{1}{A+B*T} = \frac{1}{3.8+0.0217*T}$ $(assum\ the\ burnup\ (FIMA) = 0)$

In transient state, we need more parameters for our governing equation $\rho c_p \left(\frac{\partial T}{\partial t}\right) = \nabla \cdot (\mathrm{k}\nabla\mathrm{T}) + \mathrm{Q}$. Therefore, we take $constant\ c_p = 0.33 \frac{J}{g*K}, density = 10.97 \frac{g}{cm^2}$

b. $\underline{\text{Gap} \rightarrow Pure\ He}$

In steady state (governing equation $0 = \nabla \cdot (\mathrm{k}\nabla \mathrm{T}) + \mathrm{Q}$), when we consider the constant k, the thermal conductivity is $0.0025\ \frac{W}{cm*K}$ (From the lecture note); for the temperature dependent k, the thermal conductivity is $k_{He} = 1.6 \times 10^{-5} \times t^{0.79}$, but I also set if $t < 600\ s, k_{He} = 0.002556$ to avoid the error at $t = 0\ s$.

In transient state, take $constant\ c_p = 5.193 \frac{J}{g*K}, density = 1.785 \times 10^{-4}\ \frac{g}{cm^2}$

c. $\underline{\text{Cladding} \rightarrow Zr}$

Assume the thermal conductivity of cladding is constant for our four problems, and the value is 0.17 $\frac{W}{cm*K}$ (From the lecture note.) $c_p = 0.27 \frac{J}{g*K}, density = 6.49 \frac{g}{cm^2}$

(2) Meshing:

I used the GeneratedMeshGenerator to form the whole domain, and the SubdomainBoundingBoxGenerator is used to separate the fuel, gap, and cladding blocks. In the whole domain, I take number of meshes of 1000 and 100 in x and y direction, respectively.

(3) Others:

a. The BC in the right side is set to be Dirichlet BC with the given value of the temperature of outside of the cladding $T_{CO} = 550\ K$; the BC in the left side is set to be Neumann BC $= 0$.

b. The solvers in so many examples are PJFNK, but I usually got the divergent results by using that. Eventually, I found I can use NEWTON to have efficient convergent result.