TRISO Temperature Distribution Simulation using MOOSE Framework

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1. Introduction

TRISO(Tri-structural isotropic) fuel is a multi-layered nuclear fuel with three different materials: uranium core, graphite, and silicon carbide(SiC). It is a major candidate for next-generation nuclear reactors, such as molten salt reactors (MSR). To design the reactor, we need to expect the temperature inside the TRISO which should not exceed the melting point of the outermost shell of the TRISO. Therefore, we've investigated the temperature profile of the TRISO by changing its power. This model solved the transient heat conduction equation using a MOOSE framework.

2. Methods and Results

In this section, the specific structure of the reference TRISO is described. The effect of the TRISO fuel power is described. We've found that the previous experiment concluded that the thermal expansion of the kernel is crucial to the kernel's thermal conductivity. [1-3] However, in this research, we've neglected the effect of the thermal expansion of the TRISO to understand the basic behavior. Also, we do not set the specific coolant, therefore, we do not set the boundary conditions.

The initial conditions are set as 300K to perform the fission reaction of the TRISO particle. In this simulation, we do not have a specific coolant. Moreover, the major objective of this research is to investigate the temperature profile of TRISO at the beginning of the fission reaction. Therefore, in this result, we do not consider the specific boundary conditions and consider the early stage of the fission, up to 1 second.

The transient heat conduction equation is given as equation (1) where the ρ is a density, c_p is a heat capacity, q_V is a volumetric heat generation, and k is a heat conductivity.

$$\rho c_p \frac{\partial T}{\partial t} = q_V + \nabla \cdot (k \nabla T) \quad (1)$$

The volumetric heat generation term is only applied at the kernel which is originated from the relation between the neutron flux and the energy per uranium 235 fission. Other material properties which used from the references [1-3] are also applied at each proper region.

2.1 TRISO geometry

TRISO consists of five different layers. The center of the TRISO is a kernel which is a mixture of three different nuclear fuel materials: UO_2, UC, and UC_2. The kernel is coated with low-density pyrocarbon (PyC). This low-density PyC layer is called a 'buffer'. Buffer is also coated with the other PyC. In this region, the density of the PyC is higher than the buffer. This high-density PyC layer is called as inner PyC or 'IPyC'. Outside the IPyC layer, it is coated with the silicon carbide. This layer is named after its material: the 'SiC'. Finally, the outermost layer is another layer with the high-density pyrocarbon. The name of this layer is the outer PyC, or the 'OPyC' which is similar to the IPyC.

The specific TRISO fuel geometry and material properties are obtained from the following references. [1-3]

The layered structure for the TRISO is given in figure 1. The radius of the kernel and the thickness of each layer may change depending on the documents.

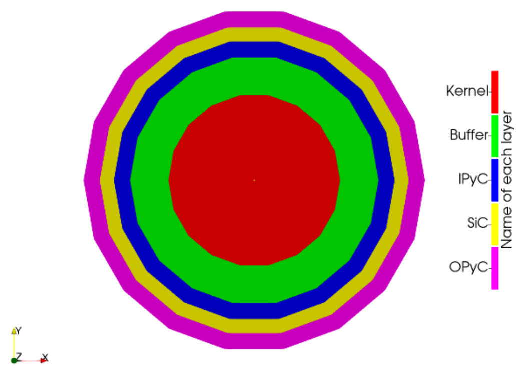

Fig. 1 The modeled TRISO using the MOOSE framework.

2.2 TRISO temperature profile

We've selected three different neutron fluxes: 10^{13}, 5×10^{13}, and 10^{14}. Figure 2 shows the general temperature profile of the TRISO particle. In this figure, we can see that there is a dramatic decrease in temperature at the buffer region. It is due to that the thermal conductivity at the buffer region is almost 10 times smaller than the others. [3]

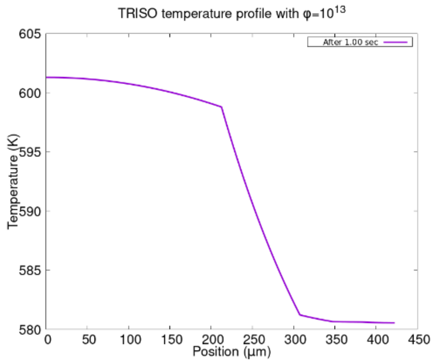

Fig. 2 General temperature profile of TRISO particle. There is a severe temperature drop at the buffer region.

Figure 3 shows the temperature profile of the TRISO with respect to the time change up to 1 second with the 10^{13} neutron/(cm^2sec) flux. In this case, the temperature increment at the TRISO center gets smaller along with the reaction time. Each temperature profile in fig. 3 is similar to the temperature profile in fig. 2. Therefore, there are no severe differences in temperature profile with respect to the time.

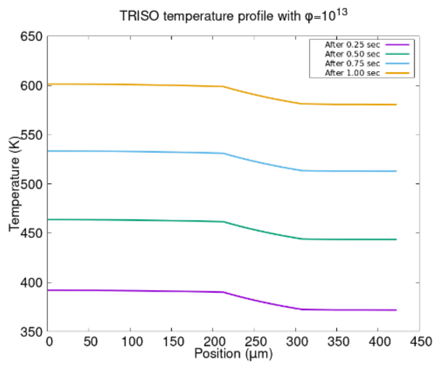

Fig. 3 Temperature profile of the TRISO with respect to the time change.

The next figure shows the temperature difference at each point with the surface temperature. In figure 4, the differences are negligible at other points except the kernel. With this neutron flux level, the temperature increment gets larger with respect to time.

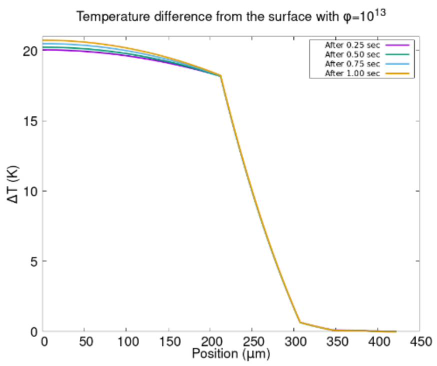

Fig. 4 Temperature difference with the surface temperature.

2.3 Effect of the neutron flux for the kernel temperature profile

At the section 2.2, the temperature profile is almost the same except for the kernel region. In this section, the effect of the neutron flux will be discussed.

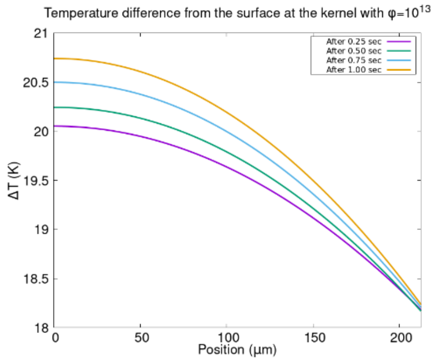

Fig. 5 Temperature difference with respect to surface temperature distribution at the kernel. The maximum temperature after 1 second is 601K.

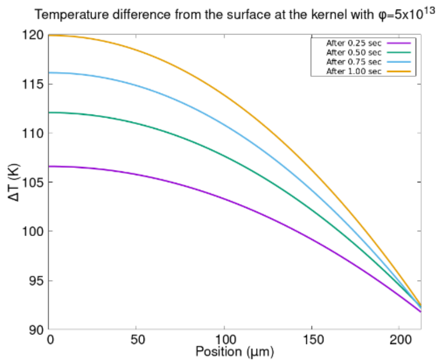

Fig. 6 Temperature difference with respect to surface temperature distribution at the kernel. The maximum temperature after 1 second is 1687K.

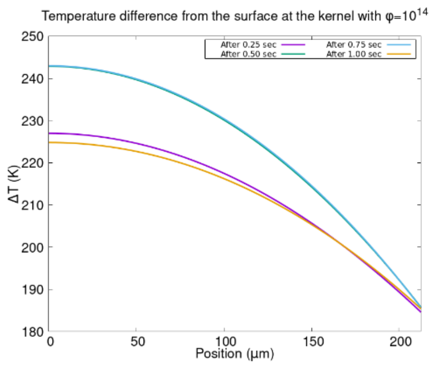

Fig. 7 Temperature difference with respect to surface temperature distribution at the kernel. The maximum temperature after 1 second is 2958K.

According to Figure 5 and 6, the temperature increment is getting larger along with the time when the neutron flux is 5×10^{13}. However, when the neutron flux is equal to 10^{14}, the temperature increment does not increase along with the time. This may be induced by the temperature limit of both heat capacity and thermal conductivity.

3. Conclusions

In this research, we've found that the TRISO particle undergoes a severe temperature drop at the buffer region. Despite we do not include the heat transfer between the TRISO particle and the coolant, this result provides a basic understanding of the TRISO internal heat transfer by using the MOOSE framework.

Along with the time, the amount of temperature change with respect to the surface temperature gets larger up to 5×10^{13} neutron/(cm^2sec) flux. In contrast, temperature differences at other layers are almost the same regardless of time.

4. Limitation and Future Work

This research has a limit since there are no interactions between TRISO and coolant. In the future, we need to consider the TRISO-coolant heat transfer, the thermal expansion of the kernel, and the compression of the buffer for a better understanding of TRISO heat transfer.

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