Analysis of VHTR Fuel Compact Cell Using Fine-Lattice Stochastic Modeling

Nam Zin Cho and Hui Yu
Korea Advanced Institute of Science and Technology, 373-1 Kusong-dong, Yusong-gu, Daejeon, Korea 305-701
nzcho@kaist.ac.kr

1. Introduction

There is growing interest worldwide in very high temperature gas cooled reactors (VHTRs) as candidates for next generation reactor systems. For design and analysis of such a reactor, transport models, in particular, stochastic models that permit the simulation of neutron transport through the stochastic mixture of fuel and moderator materials, are becoming essential and gaining importance.

In this paper, we present the comparison results of k_∞ calculations performed on a fuel compact cell in a prismatic type VHTR core. Results are generated by MCNP-4C using three models called simple homogenized (atomic-mix) model, usual coarse lattice with centered sphere (CLCS) model [1-2], and a new fine-lattice stochastic (FLS) model, respectively. The FLS model proposed for the first time in Ref. 3 is distinct from others reported in the literature. The FLS model allows: i) more realistic stochastic distribution of fuel particles than the usual lattice method, ii) ease of realization of a fuel particle distribution, and thus efficient ensemble realizations if necessary, and iii) exact preservation of fuel packing fraction.

2. Models

There are mainly two types of VHTRs that draw considerable interest, either a pebble type or a prismatic type. This paper concentrates on a triangular prism of fuel compact cell (modeled in Figure 1.) of the prismatic type VHTR [4].

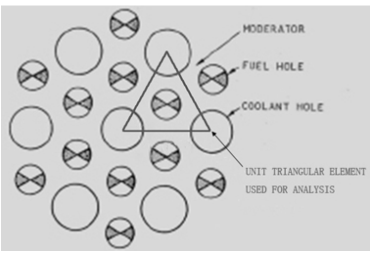

Figure 1. Fuel compact cell used for analysis

This unit cell has one fuel compact in center and three one-sixth coolant holes surrounded while in between graphite moderator is filled. The fuel compact region has an outer radius of 0.625cm, height of 5cm and consists of randomly distributed TRISO fuel particles embedded in a graphite matrix. The coolant hole has an outer radius of 0.794cm and the pitch between coolant holes is 3.4676cm. The boundary condition is set to be reflective on all sides of the triangular prism. The parameters for this unit cell are described in Table 1. The packing fraction within the fuel compact is 0.289 and the enrichment of U235 is 10.36%.

Table 1. Parameters of the fuel compact cell

Region		Material	Radius (μm)	Density (g/cc)
1	Kernel	UCO	175	10.5
2	Buffer	C	275	1.0
3	Inner PyC	C	315	1.9
4	SiC	SiC	350	3.2
5	Outer PyC	C	390	1.9
6	Matrix	C		1.0
7	Moderator	C		1.75
8	Coolant	He		0.003194

2.1 Homogenized (Atomic-Mix) Model

This homogenized model refers to a model where the heterogeneous matrix region of the fuel compact is homogenized based simply on atomic fractions. As shown in Figure 2, the left is the $z = 0$ plane schematic of the homogenized model and the right is the $x = 0$ cross sectional view.

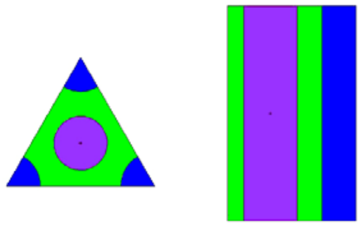
Figure 2. Homogenized model for unit fuel compact cell

2.2 CLCS Model

TRISO fuel particles are represented as centered sphere within a simple coarse lattice which is much bigger than the fuel particle itself. This appears magnified in Figure 3. In the CLCS model, number of coarse lattices is said to be equal to the number of TRISO fuel particles. Because of this, it is hard to preserve the fuel packing fraction exactly.

The cross sectional view of CLCS model for our particular unit fuel compact cell is shown in Figure 4.

2.3 FLS Model

In this new model, a "fine lattice" system is constructed so that one lattice can circumscribe a single fuel particle as shown in Figure 5. The outer diameter of a fuel particle determines the size of a fine lattice. The fine lattice could be of a cube or a hexagonal prism shape. Only the cubic lattice is considered in this paper for the moment.

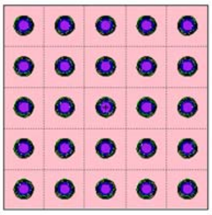

Figure 3. A view of the coarse lattice inside the compact

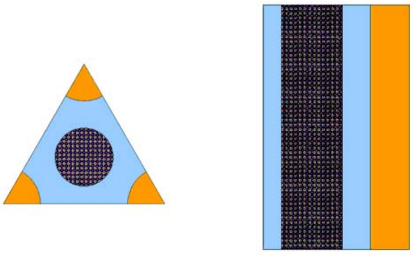

Figure 4. CLCS model for unit fuel compact cell

Then the center point of each lattice is identified, where a fuel particle can be located. What we need is the set of lattice center points.

Since the fuel packing fraction of practical application is much less than unity. There are usually more lattices than the number of fuel particles. The corresponding number of lattices as required by the fuel packing fraction is sampled from the potential candidate lattices via discrete random sampling.

Thus, the fuel packing fraction can be exactly preserved, the resulting particle distribution is more stochastic than that of the usual lattice method, and the random sampling procedure does not need checking overlap with boundaries and is very simple to check overlap with other fuel particles.

The cross sectional schematics of FLS model for the particular unit fuel compact cell are shown in Figure 6.

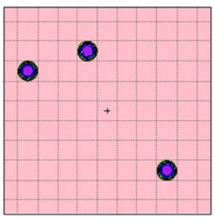

Figure 5. A view of the fine-lattice inside the compact

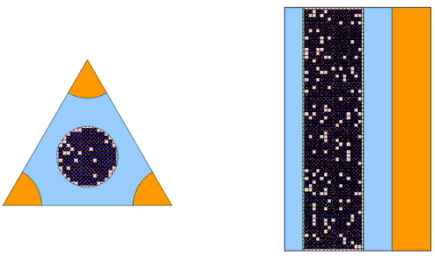

Figure 6. FLS model for unit fuel compact cell

3. Numerical results

Table 2 shows the k_∞ results for the three cases. Also shown are the relative errors. The homogenized model underpredicts k_∞ by nearly 10%. The difference between CLCS and FLS models is 0.28%. It is noted that FLS model is most accurate to the "explicit" Monte Carlo results [3].

Table 2. Criticality Results [a]

Model	k_∞	σ	Relative Error
Homogenized	1.47194	0.00051	-9.55%
CLCS	1.62276	0.00041	-0.28%
FLS [b]	1.627385	0.000125	(reference)

[a] 100 skip cycles and 1000 active cycles with 2000 histories per cycle

[b] mean value of multiple (10) realizations

4. Conclusions

This FLS model could be used conveniently to analyze the VHTR fuel element. Compared to the homogenized method and usual coarse lattice method, the FLS modeling allows more realistic stochastic distribution of fuel particles and exact preservation of fuel packing fraction. The FLS model was applied to the k_∞ calculation of a fuel compact cell in the prismatic type VHTR core, and compared to the homogenized model and the usual CLCS model. The results indicate that the FLS model is most accurate and that the homogenized model and the usual CLCS model do not provide adequate results.

ACKNOWLEDGEMENT

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