Optimization of TRISO Coating Deposition Condition on Large ZrO_2 Kernel in Conical Spouting Bed

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1. Introduction

TRISO (tristructural-isotropic) coated fuel particle is developed for using nuclear fuel for HTGR (High Temperature Gas-cooled Reactor). TRISO coating layer is generally composed of four layer of buffer PyC layer, inner PyC layer, SiC layer, and outer PyC layer. SiC layer maintains the structural integrity of TRISO coated fuel particle at high temperature and retains fission products [1,2]. Recently, fully ceramic micro-encapsulated (FCM) fuel is proposed as a nuclear fuel concept for improving the accident tolerance of light water reactor (LWR) [3,4]. FCM nuclear fuel is composed of TRISO coated fuel particle and SiC ceramic matrix. SiC ceramic matrix play an essential part in protecting fission product. In the FCM fuel concept, fission product is doubly protected by TRISO coating layer and SiC ceramic matrix. FCM fuel is also suggested as a fuel for very small high temperature gas cooled reactor due to its very high resistivity for accident. In the fuel concept for very small high temperature gas cooled reactor, the kernel size of TRISO coated particle was suggested 0.8 mm diameter as compared to 0.5 mm diameter kernel of the existing TRISO coated particle because of a long time operation. In this study, we want to fabricate TRISO coated particles with 0.8 mm large diameter ZrO_2 kernel using fluidized-bed CVD (chemical vapor deposition) method. The coating condition of TRISO coated particles was predicted with the spouting results at room temperature and its CFD (computational fluid dynamics) simulation [5].

2. Methods and Results

TRISO coated particles using 0.5 mm diameter ZrO_2 kernel were fabricated by fluidized-bed CVD method in our previous study [6]. In order to using 0.8 mm diameter ZrO_2 microsphere in a fluidized-bed CVD system, the spouting results of the microsphere at room temperature were investigated. A conical spouting bed is made of transparent polyethylene for observing spouting shape. A laser distance measurement device was used to measure the spouting height of various spherical particles.

Fig. 1 shows the image of spouting results of 14 g 0.8 mm diameter ZrO_2 particles at room temperature. As the flow rate of Ar gas increases, the spouting height of particles increases. Comparing the flow rates with the same spouting height, the flow rates of 0.8 mm particles were 2.05 times at 25 mm, 2.03 times at 30 mm, and 1.90 times at 35 mm, respectively, compared to 0.5 mm particles. Fig. 2 shows the spouting height versus spouting gas flow rate with various amounts of spouting particles. As the amounts of spouting particles increase, spouting gas flow rate increases after 14 g of spouting particles. In all conditions, the spouting heights of 0.8 mm diameter ZrO_2 particles were about half compared to those of 0.5 mm diameter ZrO_2 particles.

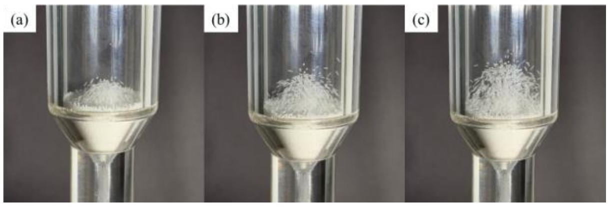

Fig. 1. Image of the spouting results of 0.8 mm diameter ZrO_2 particles at (a) 5000 sccm, (b) 7000 sccm, (c) 9000 sccm

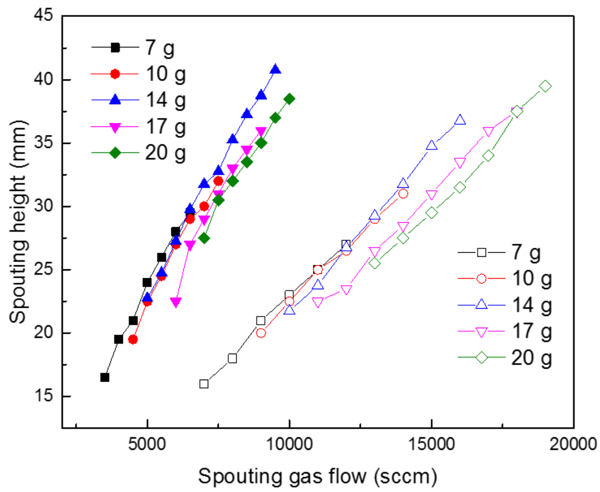

Fig. 2. The spouting height according to the spouting gas flow. Filled shapes are 0.5 mm ZrO_2 particles and empty shapes are 0.8 mm ZrO_2 particles.

Although the spouting conditions according to the particle size at room temperature were obtained through experiments, it is difficult to determine the exact experimental conditions because the production of TRISO coated particles are performed at a high temperature of more than 1400 ^oC. The spouting of ZrO_2 particles was simulated using CFD to estimate the spouting condition according to the particle size at high temperature. The spouting simulation results are shown in Park's report [5]. According to the CFD simulation results, the spouting tendency of 0.8 mm diameter ZrO_2 particles at high temperature is reported similarly to the results at room temperature.

Total flow rates of buffer PyC, inner PyC, SiC, and outer PyC in TRISO coated particles using 0.5 mm ZrO_2 kernel were 1900 sccm, 2000 sccm, 3000 sccm, 2000 sccm, respectively. The total flow rates and each source gas flow rate in TRISO coated particles using 0.8 mm ZrO_2 kernel were shown in Table 1. The ratio of the source gas used in each coating layer was kept the same. As a result of considering the particles spouting experiments at room temperature and CFD simulation, the total flow rate used in each coating layer was adjusted about 2 times as compared to the total flow of 0.5 mm kernel TRISO coated particles. The total flow rate of outer PyC coating layer was controlled 3 times because TRISO coated particles stick to the surface of the graphite nozzle at high temperature during the deposition of outer PyC coating.

Table 1. Total flow rates and each source gas flow rate of buffer PyC, IPyC (inner PyC), SiC, and OPyC (outer PyC) coating layer.

Coating layer	Q (sccm)	Ar (sccm)	C_2H_2 (sccm)	C_3H_6 (sccm)	MTS (sccm)	H_2 (sccm)
Buffer PyC	4000	2000	2000	-	-	-
IPyC	4000	2800	600	600	-	-
SiC	5400	2664	-	-	54	2682
OPyC	6000	2800	600	600	-	-

Fig. 2 shows the fractured surface and the polished surface image of TRISO coated particles using 0.8 mm ZrO_2 kernel. All coating layers were deposited successfully. Our final goal is to fabricate TRISO coated particles using 0.8 mm UO_2 kernel. Using the spouting experiments, CFD simulation and coating experiments on 0.8 mm ZrO_2 kernel, the coating condition of TRISO coated particles using 0.8 mm UO_2 kernel would be decided.

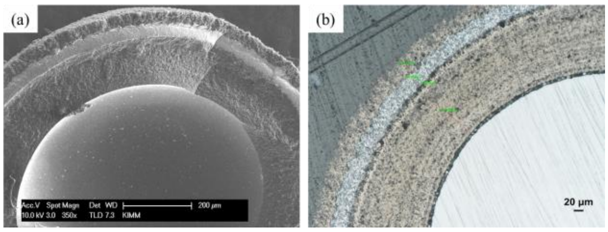

Fig. 3. The fractured and the polished surface image of TRISO coated particles using 0.8 mm ZrO_2 kernel.

3. Conclusions

The coating condition of TRISO coated particles using 0.8 mm large ZrO_2 kernel was investigated. In order to decide the coating condition, the spouting experiments in conical spouting bed at room temperature were carried out. The spouting height of 0.8 mm ZrO_2 particles is about half as compared that of 0.5 mm ZrO_2 particles. Through the spouting results and CFD simulation, it was confirmed that the flow rate for spouting 0.8 mm ZrO_2 particles at the same height is about twice that of 0.5 mm ZrO_2 particles. Considering the results, TRISO coated particles using 0.8 mm ZrO_2 kernel was fabricated with sufficient thickness.

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