Preliminary Study of 20 MWth Experiment Power Reactor based on Pebble Bed Reactor

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Abstract. In this study, preliminary design calculations for experimental small power reactor (20 MWt) based on Pebble Bed Reactor (PBR) are performed. PBR technology chosen due to its advantages in neutronic and safety aspects. Several important parameters, such as fissile enrichment, number of fuel passes, burnup and effective multiplication factor are taken into account in the calculation to find neutronic characteristics of the present reactor design.

1. Introduction

Pebble bed reactors were developed in Germany at the Juelich Research Center. The reactor produced heat by passing helium gas through the reactor core consisting of uranium fuel pebbles. A steam generator was used to generate electricity through a conventional steam electric plant.

The HTGR concept has outlet temperature of around 1,000 °C. This high output temperature enable applications such as desalination of sea water, hydrogen production, oil recovery and many other important industrial processes. There are two types of HTGR, prismatic block and pebble bed type which consist of pebble ball as the fuel. The Pebble Bed Reactor (PBR) has three fuel loading scheme: Multipass, Once Through Then Out and Peu a Peu or accumulative fuel loading scheme which have good neutronic aspect for both using uranium or thorium fuel [1-4].

Indonesia is now preparing to build Experiment Power Reactor based on PBR technology. The purposes of the present study are to analyze characteristics of selected parameters for a 20MWt Pebble Bed Reactor design that significantly contributed to the neutronic aspect, such as number of uranium enrichment, number of fuel passes, fuel loading scheme and burnup.

2. Calculation Methods

A method of neutron transport calculations to treat randomly distributed spherical fuel elements, coated particles, pebble bed fuels, plutonium spot, etc. with the continuous energy Monte Carlo method has been developed based on the statistical geometry model [5]. In this method, the position of the fuel particles is determined probabilistically from the nearest neighbor distribution (NDD) in the process of the random walk. The NDD determined from the packing fraction of fuel particles in the fuel region. This method can deal with reactor systems which have double heterogeneous structure consisting of coated fuel particles and fuel pins or fuel pebble.

In pebble bed reactor calculation, double heterogeneity need to be treated. It consists of two kinds of spherical fuel elements i.e. coated fuel particle (CFP) distribution in the fuel ball and the other one
is the fuel balls distribution in the reactor core. These calculation methods are implemented in MVP/MVP-BURN [6-7]. For nuclear data library, JENDL 3.3 are use. [8]

Table 1. Reactor Design Specification

| Design Specification        |          |
|-----------------------------|----------|
| Reactor power               | 20 MWth  |
| Fuel                        | TRISO    |
| Active core radius          | 90 cm    |
| Active core height          | 180 cm   |
| Reflector width             | 100 cm   |
| $^{235}$U enrichment        | 7-20%    |

At the present study, simplification to the actual reactor was done by created a cylindrical core loaded by pebble fuel ball using a reference design of HTR-10 [9]. Specification of the reactor core design and coated fuel particle are shown in Table 1 and Table 2, respectively.

Table 2. Coated Fuel Particle Specification

| Fuel Kernel                |         |
|----------------------------|---------|
| Material                   | UO$_2$  |
| Radius of the kernel       | 0.250 mm|
| Density                    | 10.4 g/cm$^3$ |

| Coatings                  |         |
|----------------------------|---------|
| First Buffer Layer (PyC)  |         |
| Thickness                  | 0.09 mm |
| Density                    | 1.1 g/cm$^3$ |

| Second Layer (PyC)         |         |
|----------------------------|---------|
| Thickness                  | 0.04 mm |
| Density                    | 1.9 g/cm$^3$ |

| Third Layer (SiC)          |         |
|----------------------------|---------|
| Thickness                  | 0.035 mm|
| Density                    | 3.18 g/cm$^3$ |

| Forth Layer (PyC)          |         |
|----------------------------|---------|
| Thickness                  | 0.04 mm |
| Density                    | 1.9 g/cm$^3$ |

3. Calculation Results and Discussion
Calculation are performed to study characteristic and connections of several important neutronic parameters for 20 MWt power of the present reactor design. Effect of uranium enrichment to effective multiplication factor are investigated at different pebble fuel speed through the reactor core. At the present study, 0.5, 0.75 and 1.0 cm/day pebble fuel speed are taken into account. Parametric survey for 7-20% uranium enrichment are performed and calculation results are shown in Fig. 1.
Figure 1. Characteristic of pebble fuel speed with five passes fuel loading scheme and minimum uranium enrichment needed for different fuel speed (0.5, 0.75 and 1.0 cm/day)

From the obtained data, for 0.5 cm/day fuel speed and 5 passes of pebble fuel ball through the reactor core, it will need at least 15% of uranium enrichment. Smaller number of fuel passes will need smaller uranium enrichment as shown in Fig.1. If one increased pebble fuel speed to 0.75 cm/day, minimum uranium enrichment needed will be at least 13%. For pebble fuel speed of 1.0 cm/day, minimum number of uranium enrichment is 12%. From these calculation results, correlation and optimum configuration for uranium enrichment, number of fuel passes and pebble fuel speed through the reactor core can be obtained.

Figure 2. Characteristic of number of uranium loaded to the pebble fuel, pebble fuel speed with five passes fuel loading scheme and maximum burnup with minimum uranium enrichment needed for different fuel speed (0.5, 0.75 and 1.0 cm/day)
Burnup level is also one of the important parameters in reactor design. For the present reactor design, burnup and number of burned U235 for each configuration are shown in Fig.2. For fuel speed of 0.5 cm/day with 15% of uranium enrichment and 5 fuel passes, burnup is 56 GWD/T. For 0.75 cm/day fuel speed with 13% uranium enrichment and 5 fuel passes, burnup is 37 GWD/T. For 1.0 cm/day with 12% of uranium enrichment and 5 fuel passes, burnup is 28 GWD/Ton. If one need higher burnup, for example 80 GWD/T, one could increase number of pebble ball fuel passes through the reactor core or slowing down the fuel speed.

4. Conclusion
Parametric calculations for small power 20 MWt Pebble Bed Reactor have been performed in the present study. Uranium enrichment, number of pebble ball fuel passes and pebble fuel speed through the reactor core are important neutronic parameters taken into account. From the calculation performed in the present study, highest burnup could be obtained for combination of 0.5 cm/day pebble fuel speed, 15% uranium enrichment and 5 fuel passes. It is can be also understood from the calculation general characteristic and correlation between fuel speed, uranium enrichment and number of fuel passes.

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