# A Thermal Analysis for a Fuel Element of a Pebble-Bed Reactor

Y. M. Kim* and M. S. Cho
*Nuclear Hydrogen Reactor Technology Development Division, Korea Atomic Energy Research Institute*
*P.O. Box 105, Yuseong-gu, Daejeon, 305-600, Republic of Korea*
**Corresponding author: nymkim@kaeri.re.kr*

## 1. Introduction

A fuel element called a pebble is used in a pebble-bed type high temperature gas-cooled reactor (HTGR). It stabilizes coated fuel particles (CFPs) in its inside, protects the CFPs from exterior impacts, and provides a good heat transfer medium from the CFPs into a coolant. The pebble is a spherical matrix graphite matrix which is 6 cm in diameter. The CFPs are contained in the region of which radius is less than 5 cm. The temperature distribution in a pebble is necessarily analyzed since it greatly affects the fission product migration in a pebble and a CFP. This study describes a numerical modeling for the evaluation of the temperature distribution in a pebble. A thermal analysis code for a pebble, COPA-PEBL, was developed by using a numerical modeling [1].

## 2. A Modeling for a Thermal Analysis for a Pebble

The heat in a pebble is generated from the nuclear fission of fissile materials and uranium contamination and the gamma heating of the matrix graphite, conducted through the graphite, and removed by a coolant. It can be assumed for conservative calculation that a temperature distribution within a pebble reaches an equilibrium state instantly. Then the temperature distribution in a pebble is described by a usual steady state heat transfer equation. The thermal current at the pebble center is zero on the assumption of radial symmetry. The thermal current at the pebble surface is the product of temperature difference between the pebble surface and the bulk coolant and the heat transfer coefficient of the helium gas.

A finite difference method is applied to solve the heat transfer equation for a pebble and the related initial and boundary conditions. The fuelled and non-fuelled regions of a pebble are divided into small finite difference intervals, respectively. It can be assumed that the material properties are only dependent on the time within each interval. The finite difference equations for the intervals are derived through a finite difference approximation using a point scheme [2].

## 3. Calculation Results

The thermal conductivities of CFP materials are extracted from Ref. 3. The well known Kania-Nickel correlation is used for a thermal conductivity of matrix graphite [4]. The heat transfer coefficient and material properties of helium are given by the KTA rules [5,6]. Table I shows the thickness and densities of a CFP considered. Table II displays the design parameters of an example of a pebble-bed HTGR. The A3 matrix graphite is used as a pebble material.

Fig. 1 presents the temperature distribution in a pebble, when the coolant temperature is 500 or 900 $^{o}$C and the power generation rate per particle is 18.05 mW. The temperature greatly increases with the coolant temperature. The temperature difference between the center and surface of a pebble is about 22 $^{o}$C for both cases. Fig. 2 represents the temperature distribution in a CFP at the center of a pebble. The temperature in a CFP greatly depends on the coolant temperature. Each layer except the buffer shows nearly flat temperature distribution under a normal operation condition.

Table I. Thicknesses and densities of a coated fuel particle

| Layers | Thickness (μm) | Density (g/cm$^3$) |
|---|---|---|
| OPyC | 40 | 1.90 |
| SiC | 35 | 3.20 |
| IPyC | 40 | 1.90 |
| Buffer | 100 | 1.02 |
| Kernel | 500* | 10.83 |

* Diameter.

Table II. An example of a pebble-bed reactor

| Design parameters | Values |
|---|---|
| Active core height/inner diameter (m) | 11/3.7 |
| Fuel (kernel) material | $UO_2$ |
| Enrichment (%) | 8 |
| Thermal power (MW) | 400 |
| Power density (W/cm$^3$) | 4.3 |
| Inlet/outlet temperature (°C) | 500/900 |
| Coolant mass velocity (kg/s) | 185 |
| Primary coolant pressure (MPa) | 9.0 |
| Number of pebbles in a core | 450000 |
| Number of coated particles per pebble | 15000 |
| Diameters of fuel region/pebble (cm) | 5/6 |

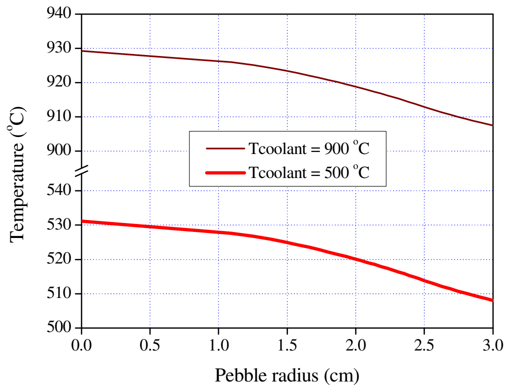


Fig. 1. Temperature distribution in a pebble according to coolant temperature.

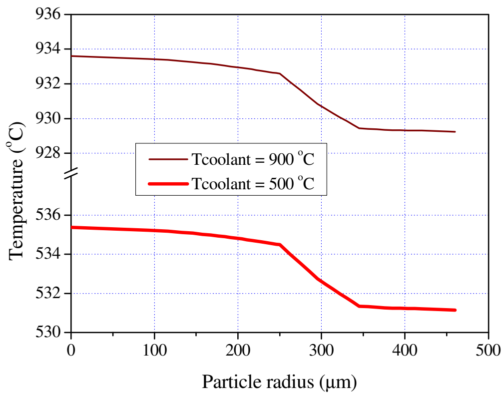


Fig. 2. Temperature distribution in a coated fuel particle at the center of a pebble according to coolant temperature.

## 4. Conclusion

A numerical modeling was set up to calculate the temperature distribution in a pebble. The computer code COPA-FPREL was developed using a numerical modeling to successfully calculate the temperature distribution in a pebble and a CFP according to a variation in the coolant temperature. Under the normal operation condition of a pebble-bed reactor, the temperature difference between the center and surface of a pebble was not large. The developed numerical modeling is applicable to the analysis of a fission product migration in a pebble and a CFP of a pebble-bed reactor.

## REFERENCES

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