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Development of an Air Ingress Analysis Module in COPA

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1. Introduction

In a high-temperature gas-cooled reactor (HTGR), air can be ingressed into a core when a primary system leaks or breaks. The air ingress into the primary system causes thermal and chemical damages to fuel materials such as graphite structure and coated fuel particles (CFPs) [1]. In the air ingress environment, the fuel materials burn off or they are chemically changed into other materials that are mechanically weaker. Thus, fission product releases increase. It is necessary to evaluate how much the fuel materials are damaged by the air ingress.

The study reviews an analysis of an air ingress in an HTGR and treats the development of an air ingress analysis module in the COPA code [2] that is an HTGR fuel performance analysis code.

2. Oxidation of fuel materials

Fig. 1 shows three oxidation kinetic regimes and their relative activation energies (slopes) [3]. Ref. [3] described the oxidation behavior by dividing it into three regimes as follows: At low temperature (Regime 1), oxidation is controlled by the chemical reactivity of the graphite. In this temperature regime, oxidation occurs uniformly in the graphite bulk, resulting in a high loss of strength and a uniform decrease in density. In the intermediate temperature region (Regime 2), the reaction rate is controlled by in-pore diffusion and the relative reactivity of the various carbon phases. In this regime, the more reactive carbon sites can react faster than oxygen can be supplied. Consequently, rate control is mixed between the chemical reaction rates and the mass transport rates. The mass transport process involves the movement of reactant gases from the graphite surface to an active site within the porous solid and the return of product gases to the outer surface. These intermediate temperature processes create a density gradient in the graphite. In the high temperature region (Regime 3), the rate of oxidation is controlled by the mass transport of the reactant gases and reaction products across the gaseous boundary layer at the outer surface of the graphite. Since the reaction takes place on the graphite surface, there is little strength loss and the graphite density remains the same.

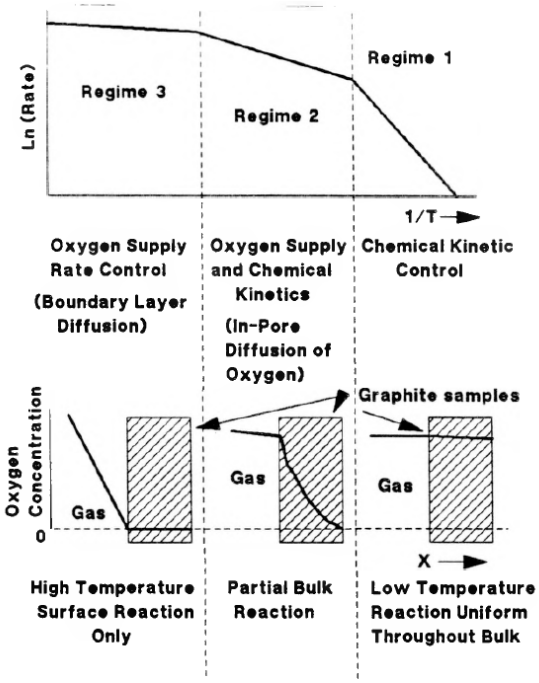

Fig. 1. Schematic display of three oxidation kinetic regimes.

3. Development of an air ingress analysis module

Fig. 2 shows a side view of a coolant channel, a graphite block and a half compact of a prismatic HTGR. Introduced air flows downward in a He coolant. The GRSAC model [4] computes graphite oxidation rates assuming both Regime 1 and Regime 3 oxidation at each node and each time step. The lower rate is selected as controlling. When Regime 1 rate is controlling, an active oxidation depth remains constant over time until the burnoff is completed in the current active oxidation depth, and subsequently a new active oxidation depth is selected. Fig. 3 shows the calculation flow of oxidation in the GRSAC model. The oxidation calculation flow is programmed in the FORTRAN programming language and the completed program is inserted into the COPA code under the module name AING.

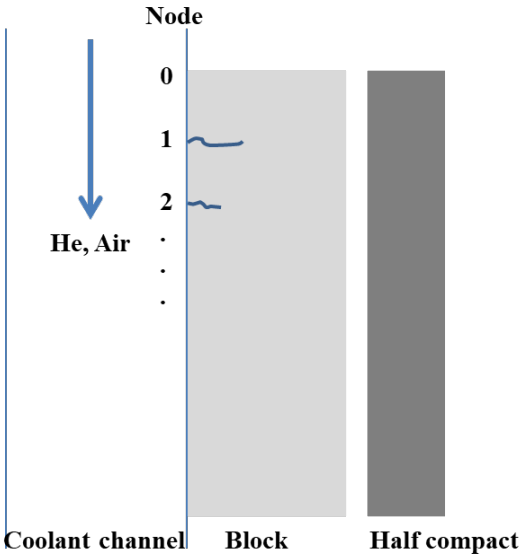

Fig. 2. A coolant channel, a graphite block and a half compact of a prismatic HTGR.

4. Calculation of oxidation of fuel materials

It was assumed that the radius of a coolant channel was 0.794 cm, the mass flow rate in a coolant channel was 0.075 kg/s, and the initial concentrations of O_2, N_2, CO_2 were 9.298×10^{-6}, 3.485×10^{-5}, 0 mol/cm^3, respectively. Graphite oxidation was calculated for 600 minutes after an air ingress starts. Fig. 4 shows the amount of graphite oxidation according to the coolant bulk temperatures. The graphite oxidation increases with the coolant bulk temperature. Figs. 5 and 6 show graphite oxidation behaviors at 600 and 800 ℃. In Figs. 5 and 6, the oxidized length is a region where all graphite is oxidized. The difference between oxidation region and oxidized length is the region currently being oxidized (hereinafter referred to as oxidizing length). Burnoff fraction means how much graphite in the oxidizing length is oxidized. At 600 ℃, there is no oxidized length and only 5.3 % of graphite is oxidized in a 4.87-mm oxidizing length. At 800 ℃, there are five oxidized lengths whose length is 2.8 mm. The limiting oxidation rate changes from Regime 1 rate to Regime 3 rate at 360 minutes.

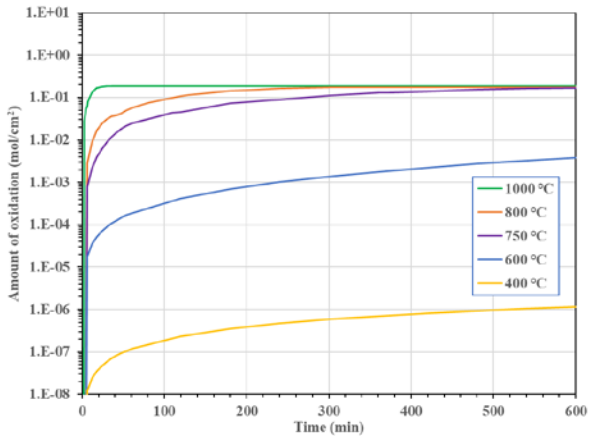

Fig. 4. Amount of graphite oxidation according to the coolant bulk temperatures.

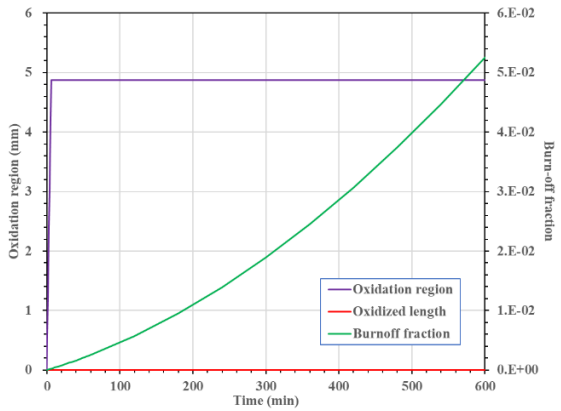

Fig. 5. Graphite oxidation behaviors at 600 ℃.

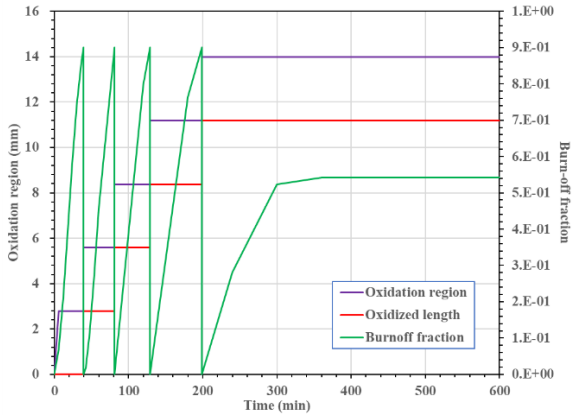

Fig. 6. Graphite oxidation behaviors at 800 ℃.

5. Summary

An air ingress analysis module is developed using the GRSAC air ingress model and it is inserted into the COPA code under the module name AING. The test calculations showed that graphite oxidation increased with temperature. Oxidized and oxidizing regions are explicitly computed. Burnoff fraction in an oxidizing region is also clearly calculated. The limiting oxidation rate is Regime 1 rate at 600 ℃. It changes to Regime 3 rate at 800 ℃. It is judged that the AING module describes well the graphite oxidation behaviors in an air ingress accident of an HTGR. The AING calculation results will be utilized to redefine the diffusivities of fission products in graphite.

ACKNOWLEDGEMENTS

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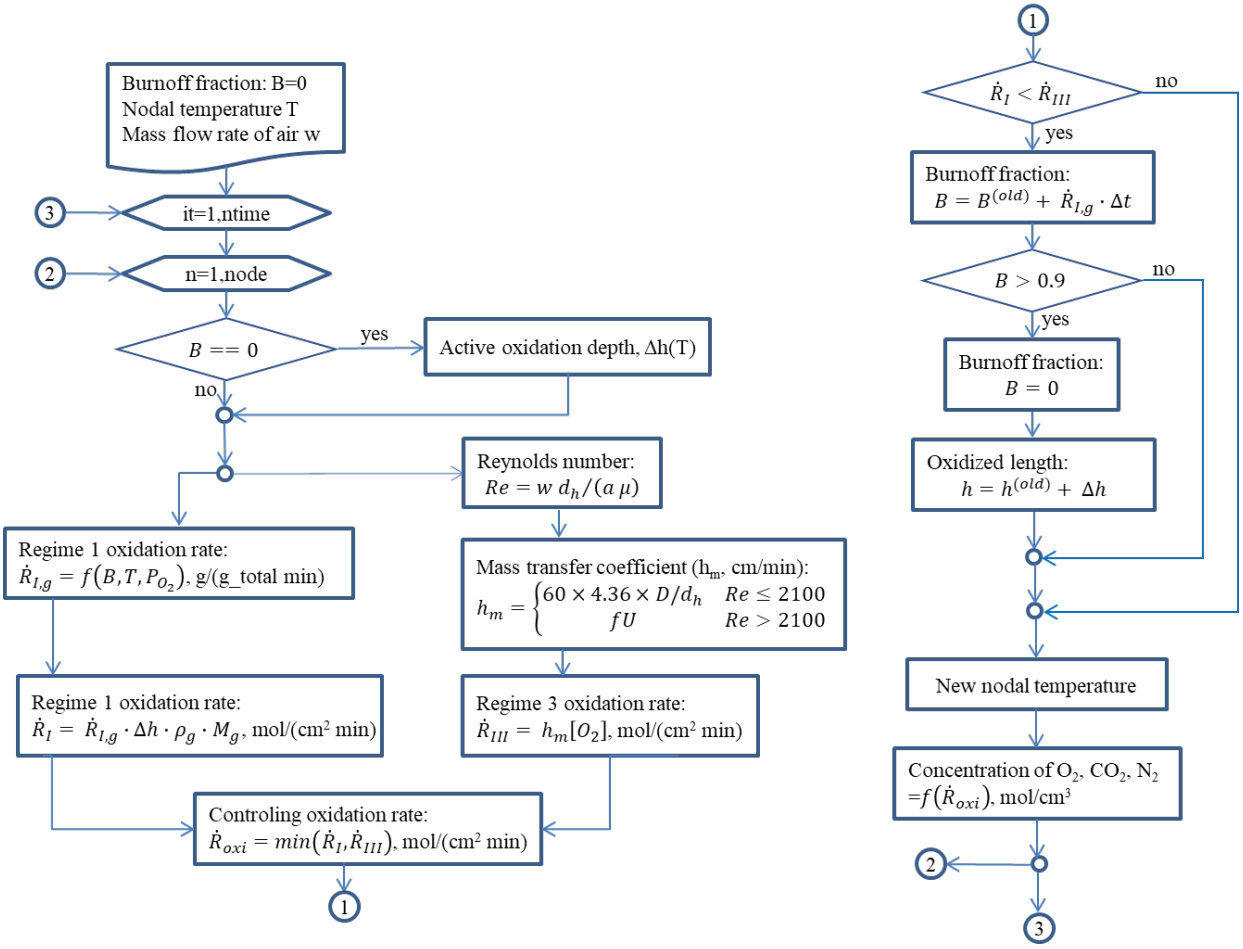

Fig. 3. Calculation flow of GRSAC air ingress model.