Numerical Analysis of the Fission Product Plate-Out Distribution in the VAMPYR-I Experiment

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1. Introduction

The plate-out behavior of fission products has been an active research filed for many years for the very high temperature gas-cooled reactors (VHTRs). Various studies have been conducted to predict the behavior since the results are responsible for public safety as well as important for the identification of a shielding area during maintenance. The plate-out deposition has also been paid much attention for core heat-up accidents due to the long time period of the event for VHTRs (e.g., several weeks). Despite the importance, however, the prediction is known to be quite challenging because there are various factors, such as surface condition, dust effect, etc., contributing to large uncertainties of the results.

In this study, a numerical analysis of the fission product plate-out distribution has been made on the experimental circuit of VAMPYR-I [2]. Based on the results, we can find some primary factors leading to the overall uncertainty of the prediction.

2. Numerical Model

2.1 Governing equation

Transport of fission products within a gaseous flow system is governed as an expression of the mass conservation throughout the coolant and surface regions. These equations are stated for each species, *i*, as follows:

$$\frac{\partial C_i}{\partial t} = q_c - \lambda_i C_i + \frac{1}{A_z}\frac{\partial}{\partial z}\left(A_z \cdot D_i \cdot \frac{\partial C_i}{\partial z} - A_z v_z C_i\right) + \frac{P_w}{A_z} \cdot h \cdot (B_i - C_i) \quad (1)$$

$$\frac{\partial S_i}{\partial t} = q_s - \lambda_i S_i - h \cdot (B_i - C_i) \quad (2)$$

(Where C: bulk concentration [m^{-3}], S: surface concentration [m^{-2}], B: boundary layer concentration [m^{-3}], P_w: wetted perimeter [m], A: flow area [m^2], q_c: volumetric direct source [$m^{-3}\ s^{-1}$], q_s: surface direct source [$m^{-2}\ s^{-1}$])

2.2 Sorption isotherms

Adsorption is usually described through isotherms as a function of pressure or concentration at constant temperature. In this study, the experimental forms of sorption isotherms were used in order to evaluate the boundary layer concentration B_i with an ideal gas law [1]. Since the mass flux between the coolant bulk and the plate-out surface is mainly affected by the concentration within the thin boundary layer, these isotherms were of crucial importance in predicting the fission product behavior near the surface of the components.

2.3 Mass transfer coefficient

The mass transfer coefficient *h* in Eqs. (1) and (2) was obtained through the heat and mass transfer analogy. Different forms of the analogy were available depending on the flow regimes.

3. Experiment and Assumptions

3.1 VAMPYR-I experiment

VAMPYR-I is a hot gas sampling tube installed in the AVR reactor in order to investigate the deposition and diffusion profiles under laminar flow conditions. The test tube had a length of 2.2m and an inner diameter of 20mm with a gas flow of 0.66g/s [1]. A schematic of the test loop is shown in Figure 1.

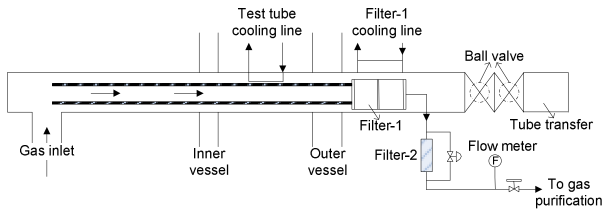

Figure 1. VAMPYR-I test facility

3.2 Assumptions for calculation

Calculation works were carried out for the runs of V09 and V12 of the VAMPYR-I experiment since they have sufficient experimental data available. Temperature profiles used in the calculation were obtained from the reference [2]. In addition, plate-out distributions along the test tube were investigated for I-131 and Cs-137, which are considered important from the viewpoint of the VHTR design.

4. Discussions & Results

Figures 2 and 3 show the predicted and measured plate-out distributions for I-131 and Cs-137, respectively. They show that the result of the plate-out activity calculated by the present work depends on the diffusion coefficient correlation to a certain degree. For I-131, a considerable amount of fission product was deposited in the downstream region with a lower temperature, and this was predicted well with the diffusion coefficient by Fuller et al. However, another diffusion coefficient suggested by GA somewhat underestimated the measured ones over the lower temperature region. This suggests that the diffusion coefficient played an important role in predicting the adsorption of I-131 over the region. On the one hand, the measured data of Cs-137 was mainly located between the two results calculated by the two diffusion coefficient formulas.

In order to investigate the effects of the surface oxidation, additional calculations were done with the sorption parameters with the oxidized surface condition [1]. The oxidized surface condition was assumed only for the high temperature region over 400°C. Figure 4 shows the effect of surface oxidation on the plate-out activities of I-131. A significant reduction was observed on the high temperature region, and it indicates that the oxide layer on the surface significantly affected the plate-out amount of I-131. It shows the maximum difference of about 100 times according to the surface conditions. From the results, it can also be found that the inner surface of the test tube in VAMPYR-I could not be severely oxidized.