Development of Water Chemistry Model in Crud Layer on Fuel Cladding

Byung Gi Park [a*], In Hyoung Rhee [a], Gwang Hong [a], Bum Young Jung [a], W. Y. Maeng [b]
[a]*Department of Energy and Environmental Eng. Soonchunhyang Univ.,Asan, Republic of Korea*
[b]*KAERI,*
[*]*Corresponding author:byunggi@sch.ac.kr*

1. Introduction

A number of pressurized water reactors (PWRs) operating at high duty and with long fuel cycle have shown axial offset anomaly (AOA) phenomena.[1] AOA is caused by a boron enrichment in a porous crud in the upper part of the core. Previous researches exhibit that this would be affected on enhanced sub-cooled nucleate boiling and porous crud buildup on the fuel cladding at high duty plants.[1] Several hypotheses have been suggested to explain boron enrichment mechanism but they are not clearly explained boron enrichment. Water chemistry model within the porous crud is required to understand boron hideout mechanism and to assist an optimization of water chemistry in reactor coolant system to mitigate AOA phenomena. The objective of the research is to develop water chemistry model within the porous crud to estimate the effects of water chemistry in reactor coolant system on AOA occurrence.

2. Methods and Results

The computational model for simulation of water chemistry in the porous crud has been developed using a two dimensional wick boiling model [2] that coupled thermal hydraulics, water chemistry, and mass transport under high temperature environments. The crud layer has a structure with chimney and porous media under boiling condition. [3] The crud layer is assumed to have porous media and chimney as shown in Fig. 1. Unit cell was selected to calculate water chemistry in the crud layer.

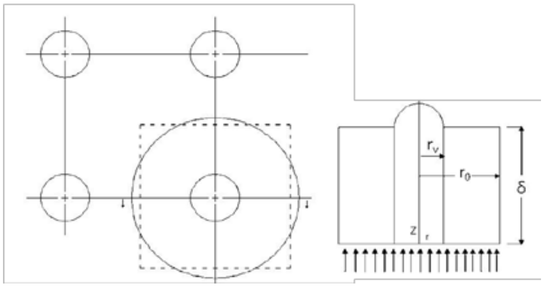

Fig. 1 Geometry model of the porous crud layer

2.1 Computational Model

Heat transfer model used an effective thermal conductivity in the porous crud that is modeled with Maxwell formula. Water velocity is obtained using Darcy's law in the porous crud. Water flux between the porous crud layer and chimney resulted from the water evaporation and used to calculate temperature profile and water velocity profile. Mass transport in the porous crud was modeled with Nernst-Planck equation. Chemical reactions such as water radiolysis, water dissociation, and boric acid reaction were included in the model.

The model calculates the effect of soluble species and temperature on physicochemical properties such as density, evaporation enthalpy, and saturation temperature that affect on heat transfer and species concentration. The model can evaluate changes of water chemistry under high temperature porous media environment, appropriately.

2.2 Results

Preliminary calculation using the computational model has been executed for porous crud with chimney of 2.5μm radius and 3,000/mm^2 density. The model calculated water chemistry in the porous crud that has thicknesses of 25μm, 30μm, and 40μm. Fig. 2 shows typical temperature profile in the porous crud layer. The results exhibit that maximum temperature in the cruds with different thickness has small difference of about 2.5 K. This will be resulted from the higher evaporation surface area of the thicker crud.

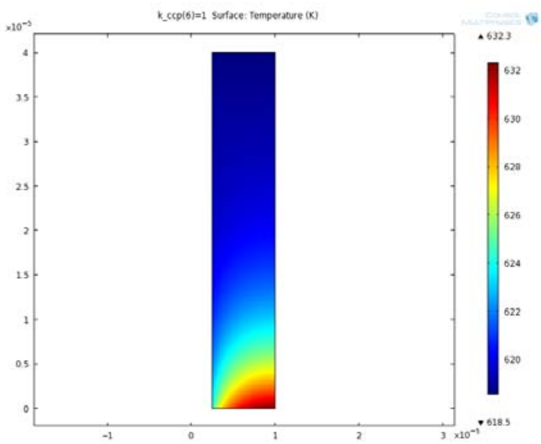

Fig. 2 Temperature profile in the porous crud layer with 40μm thickness

Fig. 3 shows the typical boron concentration profile in the porous crud layer. Boron concentration has a maximum at chimney wall near the bottom of the crud. Thicker crud has higher boron concentration. The results exhibit that precipitation of $LiBO_2$ increases forward to the bottom of the crud. This will be occurred by retroverse solubility of $LiBO_2$ and boron enrichment.

As sown in Fig. 4, the results show that pH in the porous crud increases from coolant interface, decreases in the middle region of the crud and then increase near the bottom of the crud. pH at the bottom of the crud has a trend of increase radially from chimney wall.

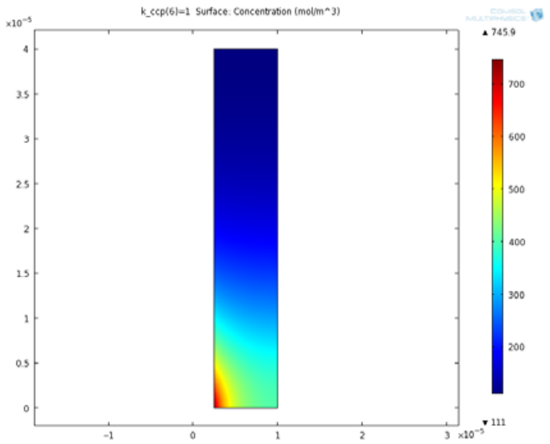

Fig. 3 Concentration profile of boric acid in the porous crud layer with 40 μm thickness

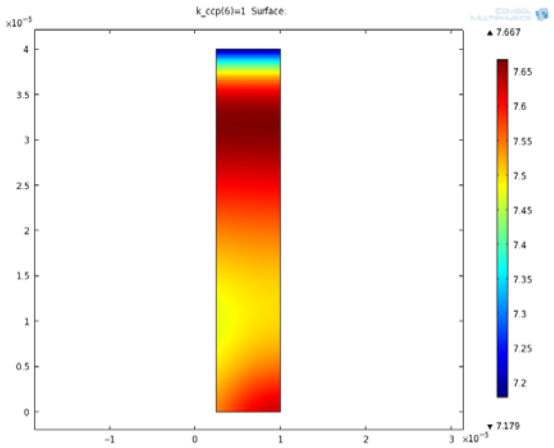

Fig. 4 pH profile in the porous crud layer with 40 μm thickness

3. Conclusions

The water chemistry model in the crud layer has been developed in the basis of two dimensional wick boiling model. The model calculates the effect of soluble species and temperature on physicochemical properties such as density, evaporation enthalpy, and saturation temperature that affect on heat transfer and species concentration. The model predicted the profiles of temperature, water velocity, concentrations of chemical species, and pH. The calculated results show that precipitation of $LiBO_2$ increases forward to the cladding surface and most of $LiBO_2$ is precipitated within 10μm thickness from the cladding regardless of crud thickness.

REFERENCES

[1] Root causes investigation of axial offset anomaly, EPRI, Palo Alto, CA USA, TR-108320, 1997.

[2] C. Pan, B.G. Jones, A.J. Machiels, "Wick Boiling Performance in Porous Deposits with Chimneys", ASME/AIChe/ANS National Heat Transfer Symposium on Multiphase Flow and Heat Transfer, Denver, August 1985.

[3] M. Zmitko, et al., "Corrosion product deposits on cladding material", Water Chemistry and Corrosion Control of Cladding and Primary Circuit Components, IAEA-TECDOCS-1128, pp. 185-194, 1999.

[4] S. Dickinson, J. Henshaw, J.C. McGurk, H.E. Sims, "Modeling PWR fuel corrosion product deposition and growth process: Final Report", EPRI, Palo Alto, CA: 2005. 1011743.