Development of EBS Modules for a Process-based Total System Performance Assessment of a Geological Disposal System

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1. Introduction

Recently, KAERI has proposed developing a process-based total system performance assessment model for a geological disposal system (APro which stands for "**A**dvanced **Pro**cess-based total system performance assessment framework for a geological disposal system") to cope with the limitations of system-level model to reflect short- and long-term evolution of the disposal system and to realistically simulate thermal, hydraulic, mechanical, and chemical complex phenomena.

As the first step of development of the model, the modeling interface was designed in the previous study [1]. For further works, in this study, the EBS-related modules, such as radioactive decay heat and thermal transfer, canister corrosion, and radionuclide release, were developed and embedded into APro.

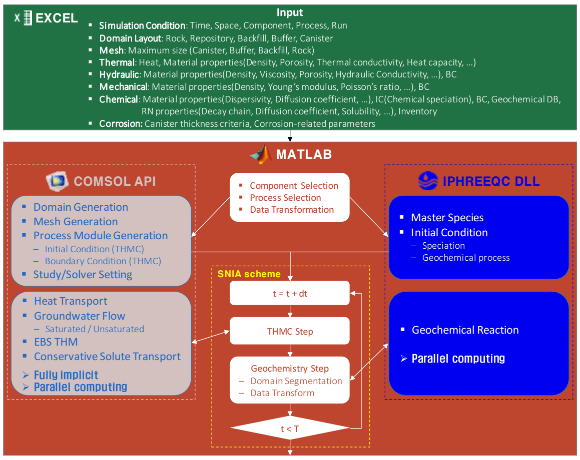

Fig. 1. Flowchart of APro.

2. APro

APro employs a bottom-up approach unlike a system-level model which uses top-down approach. APro was basically designed to be able to simulate all the processes that could occur in a geological disposal system including thermal, hydraulic, mechanical, and chemical (radiological) processes. The flowchart of APro is depicted in Fig. 1.

2.1 APro's Thermal Transfer Module

APro's *Default Process* with respect to the thermal transfer assumes that the EBS and NBS are fully saturated. The thermal transfer in fully-saturated porous media is governed by the following equation:

$$(\rho C_p)_{\mathrm{eff}}\frac{\partial T}{\partial t} + \rho C_p \mathbf{u}\cdot\nabla T + \nabla\cdot\mathbf{q} = Q \quad (1)$$

$$(\rho C_p)_{\mathrm{eff}} = (1-\varepsilon_{\mathrm{p}})\rho_{\mathrm{p}}C_{p,\mathrm{p}} + \varepsilon_{\mathrm{p}}\rho C_p \quad (2)$$

$$\mathbf{q} = -\{(1-\varepsilon_{\mathrm{p}})k_{\mathrm{p}} + \varepsilon_{\mathrm{p}}k\}\nabla T \quad (3)$$

where, T is temperature, ρ is density of water, ρ_{p} is density of solid, C_p is heat capacity of water, $C_{p,\mathrm{p}}$ is heat capacity of solid, ε_{p} is porosity, $\mathbf{u}$ is Darcy velocity of water, k is thermal conductivity of water, k_{p} is thermal conductivity of solid, and Q is heat source.

As the heat source, decay heat of the reference spent fuel whose initial enrichment is 4.5wt% and burnup is 55 GWd/MtU was considered as the following regression equation [2].

$$Q = C_0 + C_1 e^{-\frac{t-t_0}{t_1}} + C_2 e^{-\frac{t-t_0}{t_2}} + C_3 e^{-\frac{t-t_0}{t_3}} \quad (4)$$

Table. 1. Coefficients of decay heat regression equation

t	1yr< t ≤100yr	100yr< t ≤1,000yr
C_0	297.9526	32.1858
t_0	0.7805	101.6499
t_1	2.9441	40.5612
t_2	1.0966	121.288
t_3	42.7499	622.1932
C_1	3,218.383	146.7649
C_2	10,394.94	110.4017
C_3	2,036.431	197.2185

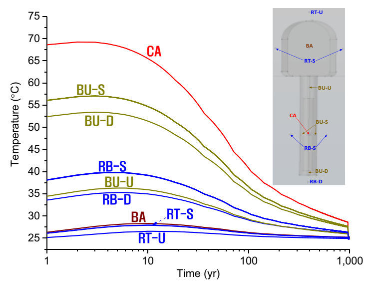

Fig. 2. Temporal distributions of temperature around EBS.

For the single borehole of the KRS, the temporal distributions of temperature around EBS are depicted in Fig. 2. From the result, the peak of temperature was observed within 10 years, and the highest temperature was less than about 70°C.

2.2 APro's Canister Corrosion Module

APro's *Default Process* with respect to the canister corrosion assumes that every canister is failed after a certain life-time. Before the canister failure, the canister is considered as an impermeable barrier. Once the canisters are failed, the radionuclide release will commence.

Fig. 3 shows the change of Darcy velocity after canister failure.

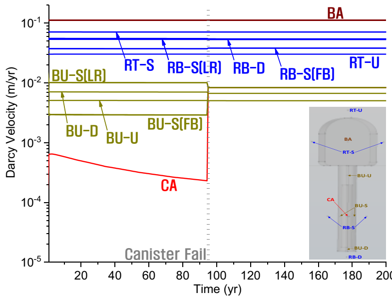

Fig. 3. Temporal distributions of Darcy velocity around EBS.

APro's *Alternative Process* with respect to the canister corrosion considers copper oxidation by dissolved oxygen in groundwater as follows.

$$4\mathrm{Cu} + \mathrm{O}_2 \rightarrow 2\mathrm{Cu}_2\mathrm{O} \tag{5}$$

From the reaction, the change of canister thickness can be computed by the following equation:

$$\frac{\partial \tau_{\mathrm{Cu}}}{\partial t} = -\frac{R_{\mathrm{Cu|O_2}} \cdot Q_{\mathrm{O_2}} \cdot W_{\mathrm{Cu}}}{\rho_{\mathrm{Cu}}} \tag{6}$$

where, τ_{Cu} is canister thickness, $R_{\mathrm{Cu/O2}}$ is the reactant ratio, Q_{O2} is influx of dissolved oxygen, W_{Cu} is atomic weight of Cu, and ρ_{Cu} is density of Cu. The concentration of dissolved oxygen at the canister surface is constant as 0 mol/m^3 since it is assumed that all dissolved oxygen at the canister surface is consumed with copper oxidation.

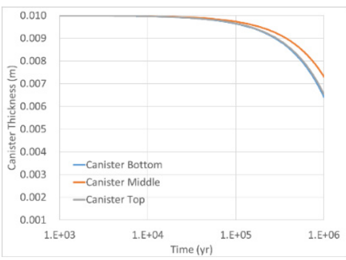

Fig. 4. Temporal distributions of canister thickness.

Fig. 4 shows the temporal distribution of canister thickness for a certain condition.

2.3 APro's Radionuclide Release Module

APro's *Default Process* with respect to the radionuclide release assumes the solubility-limited release for the radionuclides having finite solubility and the instant release for the radionuclides having infinite solubility. The solubility-limited release can be computed by the following equation:

$$Q_n = \min(C_{0,n}, S_n) \cdot \boldsymbol{q} \tag{7}$$

where, Q_n is radionuclide release rate, $C_{0,n}$ is radionuclide inventory, S_n is radionuclide's solubility, and $\boldsymbol{q}$ is Darcy flux in the canister. And the radionuclide inventory will be changed as follows:

$$\frac{\partial C_{0,n}}{\partial t} = \Lambda C_{0,n} - Q_n \tag{8}$$

where, Λ is the matrix of radioactive decay chain.

3. Conclusion

In this study, the EBS-related modules, such as radioactive decay heat and thermal transfer, canister corrosion, and radionuclide release, were developed and embedded into APro. Through the development, it is expected that the coupling effects of EBS-related processes can be confirmed in the future. For further work, the EBS THM processes will be added into APro in the near future.

ACKNOWLEDGEMENT

This work was supported by the Nuclear Research and Development Program (No. 2017M2A8A5014856) of the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (MSIT).

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