COUPLED MULTIPHASE FLOW TRANSPORT IN DEFORMABLE ROCK WITH CONSIDERATION OF MICROBIOLOGY

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Summary A new coupled hydro-chemo-bio-mechanical model for unsaturated porous media with consideration of chemical osmosis flow, microbial growth, metabolic decay and endogenous has been developed. This new coupled formulation may be applied to a number of research areas such as Nuclear waste disposal, CO2 disposal and Oil drilling wellbore stability analysis.

INTRODUCTION

In nuclear waste disposal research area, the influence of microbes on the radionuclides transport might be very important. In this paper, the interact impacts between the microbial kinetics, the consumption of radionuclids by microbes, the transport of radionulcides and water flow, and the deformation of the rock have been analyzed. Furthermore, since low permeability rock/clay has the potential to behave as an actual semi-permeable osmotic membrane, chemical osmosis has a very strong effect on water flow and needs to be accounted in analysis.
Microorganisms related reactions are very important in Geochemistry and Geomicrobiology because by which numerous organic and inorganic compounds might be metabolized or transformed. The bacteria's capabilities and the environment conditions such as temperature, salinity, PH, availability of oxygen might have strong influence on the end products. Biodegradation is the chemical breakdown of materials (e.g. organic material, radionuclides and metals) by environment. Microbial biodegradation (e.g. Aerobic biodegradation, Anaerobic biodegradation, Fungal biodegradation etc.) of pollutants have attracted attention in cleaning up contaminated environments in recent years [1].
Engineering barriers and host rock for I/LW should have high sorption properties to prevent the migration of radionuclides, which might leak from a radionuclides repository. The capacity of sorption of radionuclides is a key character of Engineering barrier in safety analysis for nuclear waste disposal [2-4]. Sorption is a combination of physical and chemical processes. It covers all surface related reactions such as absorption, adsorption, surface complexation, surface precipitation and ion change. The details of sorption mechanisms can be found in reference [5].
This paper analyzes the influence of Biogeochemical process in the coupling of hydro-chemo-bio-mechanical and provides a new formulation for such coupled modeling.

CONSTITUTIVE COUPLED FORMULATION

Solid Phases

Since the attention of this paper is focused on Biogeochemical coupling, the simplest elasticity formulation for solid deformation has been adopted in the following description,

$$G\nabla^2\dot{\mathbf{d}}+\left(\frac{G}{1-2\nu}\right)\nabla(\nabla\cdot\dot{\mathbf{d}})-\zeta\nabla\dot{\bar{p}}=0$$

in which G is the rock shear modulus, ν is Poisson ratio, the quantity ζ is related to the bulk moduli K and K_s in a poroelastic manner, $\bar{p}$ is the average pore pressure.

Fluid phase

The chemical osmosis, which can cause the water flow from lower chemical concentration to higher chemical concentration, has been accounted in the following fluid transport formulation

$$S^f\zeta\nabla\cdot\dot{\mathbf{d}}+S^fQ(S^f+\frac{C_s}{\phi}p)\frac{\partial p}{\partial t}+(C_S+\phi\frac{S^f}{K_w})\frac{\partial p}{\partial t}+\left[-\nabla\cdot k\frac{k_{rw}}{\theta}(\nabla p-\rho_t^f r\frac{RT}{M^c}\frac{1}{C^cC^w}\nabla C^c)\right]=0$$

which S^f is the saturation of fluid (not including gas), Q is here assumed to be material-dependent constants, C_S is the moisture content, P is the fluid pressure, K_w is the bulk modulus of water, k is the absolute permeability, k_{rw} is the relative permeability, r is the reflection coefficient, T is the temperature, M^c is the molar mass of the chemical, C^c and C^w are the mass fraction of chemical (radionuclides) and water, respectively.

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Radionuclides transport

The possible effects of microorganisms on the performance of engineered barrier and host rock might be summarized as follows [1]: (1): positive effects: microorganisms might immobilize radionuclides by absorbing and accumulating soluble elements; biofilms might act as an barrier in addition to Engineered barriers; excretion of polysaccharides might affect the physical performance of Engineered and natural barriers by closing or reducing the pores in clay, sandstone or host rock. (2): Negative effects: microbes might facilitate transport by excrete insoluble complex into soluble iron. Since the influence of microorganisms on nuclear repository is still on the fore front research, there might be more positive or negative effects which can be discovered in the future research. The new radionuclides transport formulation can be derived as

$$S^f \phi \dot{C}^c - \left[k \frac{k_{rw}}{\theta} (\nabla p - \rho_t^f r \frac{RT}{M^c} \frac{1}{C^c C^w} \nabla C^c) \right] \cdot \nabla C^c - L \nabla \left(\frac{1}{p} \nabla p \right) - D \nabla^2 C^c - S^f \phi R_b = 0$$

In which L is the coupling coefficient of pressure, D is the diffusion coefficient of chemical, while Rb is the function of sink caused by microbes.

Microbes kinetics

In nuclear waste disposal research, since microbial biodegradation might help reduce radionuclides or metals transport, some experiments have been conducted to analyze the effects of microbial activity on the near and far fields for a Swiss L/ILW repository, and to analyze the cross effects on structures, geochemistry, radionuclides sorption.

There might be three processes for biodegradation such as microbial growth, metabolic decay and endogenous respiration. Thus, the total rate can be defined as the sum of three progresses as [6-8].

$$\frac{\partial C_b^i}{\partial t} = \left. \frac{\partial C_b^i}{\partial t} \right|_{growth} + \left. \frac{\partial C_b^i}{\partial t} \right|_{decay} + \left. \frac{\partial C_b^i}{\partial t} \right|_{endogenous}$$

where C_b^i is the concentration of microbes which related with the growth, decay and endogenous formulations.

CONCLUSION

A coupled new formulation for hydro-chemo-bio-mechanical has been derived. A three dimensional numerical modelling has been performed and will be shown on the presentation. The result shows that microbes might have an important impact on the radionuclides transport.

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