Reservoir-scale simulation for salt-deposit dissolution with a diffuse interface model

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Abstract A diffuse interface model (DIM) based on a porous medium theory is used to simulate the reservoir-scale salt deposit dissolution problems. The solid-liquid interface is artificially diffused according to the local non-equilibrium model. An adaptive mesh refinement method is applied to track the moving fronts, in order to maintain fine grids around the interfaces but coarser grids elsewhere. Numerical results show that the reservoir-scale dissolution problems can be simulated efficiently by this DIM method.

INTRODUCTION

Solid-liquid dissolution is a typical problem with a moving interface, e.g., salt-deposit dissolution. Two classes of numerical methods, e.g., sharp interface methods and diffuse interface methods (DIM), can be utilized to simulate this kind of problem. Normally, the former methods are difficult to handle the complex geometry of interfaces, while the latter methods are more convenient as they consider the interface as a diffuse layer where the physical quantities vary continuously. Therefore, DIM models are preferred in most of simulations. Generally, most of DIM works are based on the Cahn-Hilliard model. However, using real fluid characteristic leads to a physical interface, which is very thin for solid-liquid dissolution. Very huge grid number is thus required to capture the narrow interface. Therefore, the corresponding computations are often limited to a very small spatial scale, which could not meet the need for larger scale simulations. In this paper, we utilize a completely different DIM model, which is based on a porous medium theory [1], considering the solid-liquid interface as a porous medium transition whose porosity varies from 0 to 1. According to a local non-equilibrium model, the fronts can be artificially diffused, thus a larger grid size can be adopt. Consequently, reservoir-scale simulations are able to be implemented by this DIM method. In addition, adaptive mesh refinement (AMR) method [2] can be applied to improve the computation efficiency. In the following sections, we introduce the diffuse interface model and present the simulation results.

DIFFUSE INTERFACE MODEL

The mass balance equations for liquid phase, solid phase, and salt can be written by Eq. 1-3, respectively.

$$\frac{\partial \varepsilon_\beta \rho_\beta^*}{\partial t} + \nabla \cdot \left(\rho_\beta^* \boldsymbol{V}_\beta\right) = \rho_\beta^* \alpha \left(\omega_{eq} - \Omega_{A\beta}\right) \tag{1}$$

$$-\rho_\sigma^* \frac{\partial \varepsilon_\sigma}{\partial t} = \rho_\sigma^* \frac{\partial \varepsilon_\beta}{\partial t} = \rho_\beta^* \alpha \left(\omega_{eq} - \Omega_{A\beta}\right) \tag{2}$$

$$\varepsilon_\beta \rho_\beta^* \frac{\partial \Omega_{A\beta}}{\partial t} + \rho_\beta^* \boldsymbol{V}_\beta \cdot \nabla \Omega_{A\beta} = \nabla \cdot \left(\varepsilon_\beta \rho_\beta^* \boldsymbol{D}_{A\beta}^* \cdot \nabla \Omega_{A\beta}\right) + \rho_\beta^* \alpha \left(1 - \Omega_{A\beta}\right)\left(\omega_{eq} - \Omega_{A\beta}\right) \tag{3}$$

where β refers to the liquid phase, σ refers to the solid phase, ε_β is the volume fraction of liquid phase, $\Omega_{A\beta}$ is the mass fraction of salt, ω_{eq} is the equilibrium concentration of the salt, α is the exchange coefficient between the solid phase and liquid phase, and $D_{A\beta}$ is the effective diffusion coefficient. Darcy-Brinkman method can be used to calculate the liquid velocity $\boldsymbol{V}_\beta$.

NUMERICAL SIMULATION

Figure 1 shows an example of salt-deposit production. Pure water is injected from an inner tube at the top while salt solution is produced from the outer tube at the same time. This problem can be simplified into a two-dimensional axis-symmetric problem. We utilized a DIM model to simulate the procedure. AMR method is also applied to follow the moving interfaces, in order to have fine grids around the fronts but coarser grids elsewhere. The simulation results until 10 days of production are shown in Figure 2. It shows a moving sharp front, where the liquid volume fraction and salt mass fraction vary sharply but continuously. The grids are fine around the fronts.

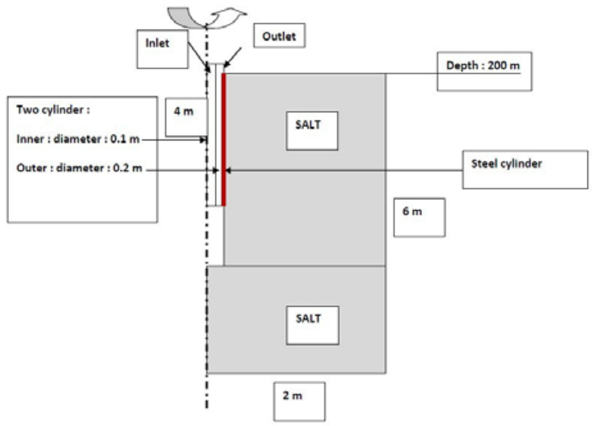

Figure 1. Shown of a salt-deposit production example

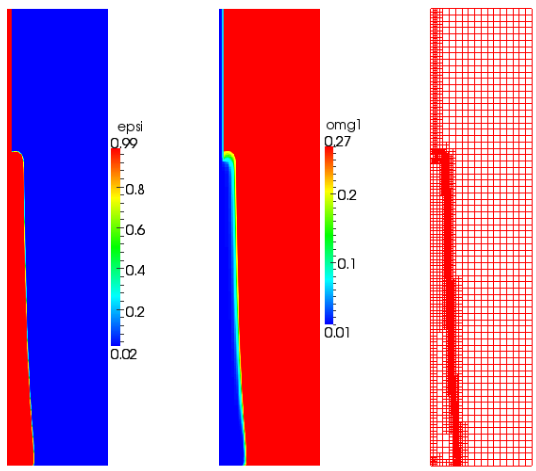

Figure 2. Simulation results are 10 days of production. (from left to right: volume fraction of liquid phase, mass fraction of salt, adaptive mesh structure)

CONCLUSIONS

Reservoir-scale simulation for dissolution problems with diffuse interface model is a difficult task. The simulation results in this paper show that the diffuse interface method is able to simulate the reservoir-scale salt-deposit dissolution problem. The solid-liquid interface is moving due to the dissolution. Fine grids are needed near the sharp moving fronts. Therefore, AMR method can improve the computational efficiency by only applying fine grid around the fronts to reduce the total grid number. It is proved that the combination of DIM and AMR is rather effective for the simulation of this kind of reservoir-scale dissolution problem. It could be extended to many applications of similar problems.

References

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