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Hydrate formation and migration in stratified porous media

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Methane often generates in fine-grained marine muds by the biodegradation of organic matter but accumulates in neighboring coarse sand layers in the form of hydrates. This phenomenon is attributed to the higher capillary pressure in mud layers than in sand layers, which makes hydrate accumulation in sand layers more thermodynamically favorable. However, rarely explored is its kinetics, i.e., how fast is methane to migrate from where it generates to where it finally accumulates. We investigate the hydrate formation and migration kinetics in stratified porous media, using a novel 1-D diffusion-reaction model. This model counts Non-Fickian diffusion induced by the temperature gradient, gravitational effect, and capillary pressure gradient, which have not been considered simultaneously in previous studies.

We first investigate a simplified scenario that consists of two neighboring mud and sand layers with identical thickness and porosity. In this scenario, capillary pressure contrast dominates over all other non-Fickian diffusion mechanisms, so the model can be highly simplified that allows for analytical solutions. A modified Da number is defined to characterize the ratio between methanogenesis rate and migration rate, that divides the methane migration kinetics into two regimes: when Da<~0.4, hydrate never cumulates in the mud layer but directly cumulates in the sand layer; when Da >~0.4, hydrate first cumulates in the mud layer but gradually migrates to the sand layer. For the latter regime, a critical time tc is identified, after which the sand layer cumulates more hydrate than the mud layer. The above analytical results match the full numerical solution well. The analytical prediction of critical Da and tc matches well with the full numerical solution.

We further conduct full simulation on a much larger system that consists of multiple different sedimental layers. The accurate description of this process requires all non-Fickian diffusion mechanisms to be accounted for. The results show that gravitational and thermal gradient gradually dominates over capillary contrast in larger temporal and spatial scales, while capillary pressure still depicts local features of hydrate distribution. This work systematically illustrates general principles of how the interplay between methane generation and migration controls hydrate saturation profile evolution in stratified porous media, which further helps in the evaluation of hydrate exploitation's feasibility.

Time Block Preference

Time Block B (14:00-17:00 CET)

References

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