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Thermo-Chemo-Hydro-Geomechanical Model and Numerical Solution Strategy for Marine Gas Hydrate Geosystems with a focus on Gas Production and related Geohazards

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Gas hydrates are crystalline solids formed when water molecules form a cage-like structure and trap a large number of gas molecules within. Gas hydrates are thermodynamically stable under conditions of low temperature and high pressure and occur in nature typically in permafrost regions and marine off-shores. If warmed or depressurized, hydrates destabilize and dissociate into water and gas.

It is widely believed that the energy content of methane occurring in the form of hydrates possibly exceeds the combined energy content of all other conventional fossil fuels put together. Natural gas hydrates are, therefore, deemed a promising future energy resource, and it is of high interest to develop technically and economically feasible methods for producing methane gas from these reservoirs. Several methods have been proposed, such as, thermal stimulation and depressurization. However, there are serious safety concerns regarding the inherent environmental and geotechnical risks associated with gas hydrate destabilization. When the gas hydrates form in natural sediments, they enhance the strength of the sediment and prevent normal consolidation. During gas production, loss of hydrates can cause rapid consolidation, uncontrolled sand migration, bore-hole instabilities and well collapse. Loss in the structural integrity of the sediment around the production well can seriously impact local and regional slope stability. Due to these process management and safety concerns, and large uncertainties associated with the properties, distributions, and hydro-geomechanical behavior of hydrate-soil fabrics, none of the proposed methods have reached the technical maturity which is necessary for large scale gas production, despite a considerable research effort in the past decades.

To make realistic assessments of the viability of any future technology for natural gas hydrate reservoirs, it is important to develop mathematical models and numerical tools that can handle highly coupled multi-physics processes in complex geological settings, and reliably quantify the uncertainties in their predictions for the relevant production scenarios.

Here, we present our modeling and coupling concept for marine gas hydrate geosystems with a focus on gas production and geotechnical risks quantification. In this context, we describe natural gas hydrate reservoirs as highly complex geological porous medium characterized by large material heterogeneities, local anisotropies, and a large number of strongly coupled multi-physics processes, including: 1) kinetically driven hydrate phase change; 2) multi-phase, multi-component fluid flows; 3) thermal effects; 4) geomechanical deformation of the sediment. Central to our coupling concept is the assumption that hydrate and soil form a single composite phase, where, soil forms the primary load bearing skeleton, while the hydrate acts as a mechanical cementing agent which only enhances the strength and stiffness of the composite solid without bearing any load itself. An important consequence of this assumption is that it allows us to define two porosities: One that evolves as a result of sediment deformation, and the other that evolves due to hydrate phase change, thereby, greatly simplifying the mathematical model.

In this presentation, we will describe our mathematical model and numerical solution strategy, and show the applicability of our model through numerical simulation of high pressure flow-through tri-axial experiments.

References

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