Modeling the behavior of gas hydrate bearing sediments

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Methane hydrates form at high pressure and low temperatures conditions typically found in submarine sediments and permafrost. Gas hydrates are solid compounds made of water clustered around low molecular weight gases (e.g. methane, ethane, and carbon dioxide). Figure 1 presents a scheme related to the hydrate stability zone in submarine sediments. Stability and behavior of Hydrate Bearing Sediments (HBS) are strongly dependent on thermo-hydro-mechanical and chemical (THMC) actions affecting the gas hydrate compound.

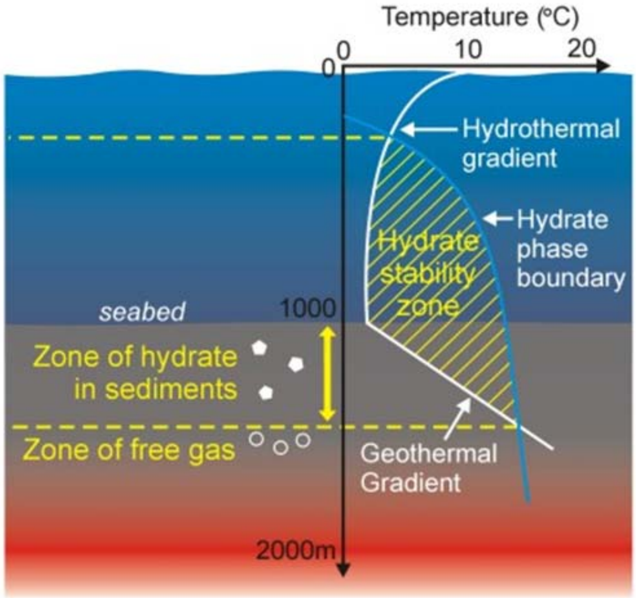

Figure 1. Presence of hydrates in a zone beneath the seabed. Modified after NETL(2015).

Methane hydrates are foreseen as a potential energy resource, as large reserves are estimated worldwide (e.g. Sloan 2007, Rutqvist and Moridis, 2007). Unstable hydrate dissociation can cause borehole instability, blowouts, foundation failures, and trigger large-scale submarine slope failures (e.g. Kayen and Lee, 1991). The release of methane would further exacerbate greenhouse effects and contribute to global warming (Dickens et al., 1997). A good understanding of the behavior of gas hydrates and the physical and chemical phenomena related to hydrate formation and dissociation are crucial to deal with engineering problems involving HBS.

The experimental investigation of natural HBS is challenging owing to the strong dependence of hydrate stability on pressure and temperature conditions. Experimental studies on reconstituted samples in the laboratory are hindered because of the very low solubility of methane in water. This situation highlights the relevance of numerical investigations and constitutive modeling in advancing the current knowledge of HBS.

The behavior of HBS is complex in nature as dissociation may take place due to an increase in temperature; a decrease in fluid pressure; changes in the fluid chemistry (that may switch the phase boundary that delimit the stability zone), or a combination of them. The dissociation process causes important variations in fluid pressures with the associated flow of gas and water. Changes in fluid pressures will affect the effective stress, which will impact in turn on the stiffness, strength and dilatancy of the sediment. From the description above, it is evident that the behavior of HBS is controlled by strong THM coupled processes.

Mathematical formulations have been proposed to model processes involving hydrate formation and dissociation within well-defined boundary conditions (e.g. Rutqvist and Moridis, 2007). In this work a fully coupled THM formulation is proposed. The process of hydrate dissociation have been modeled assuming local equilibrium conditions (i.e. the dissociation process is very fast compared to the characteristic time of the flow problem). The dependence of effective stress, stiffness, strength, conduction properties and volume change on the hydrate saturation are also implemented in the proposed framework. The mathematical formulation and the associated computer code (based on CODE_BRIGHT, Olivella et al., 1996) have been verified against analytical solutions and validated against t experimental tests. Very satisfactory agreement have been observed

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