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Response of Oceanic Hydrate-Bearing Sediments to Thermal Stresses

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Abstract

In this study we evaluate the response of oceanic subsurface systems to thermal stresses caused by the flow of warm fluids through non-insulated well systems crossing hydrate-bearing sediments. Heat transport from warm fluids, originating from deeper reservoirs under production, into the geologic media can cause dissociation of the gas hydrates. The objective of this study is to determine whether gas evolution from hydrate dissociation can lead to excessive pressure build-up and possibly to fracturing of hydrate-bearing formations and their confining layers, with potentially adverse consequences on the stability of the suboceanic subsurface. This study also aims to determine whether the loss of the hydrate – known to have a strong cementing effect on the porous media – in the vicinity of the well, coupled with the significant pressure increases, can undermine the structural stability of the well assembly.

Scoping 1D simulations indicated that the formation intrinsic permeability, the pore compressibility, the temperature of the produced fluids and the initial hydrate saturation are the most important factors affecting the system response, while the thermal conductivity and porosity (above a certain level) appear to have a secondary effect. Large-scale simulations of realistic systems were also conducted, involving complex well designs and multilayered geologic media with non-uniform distribution of properties and initial hydrate saturations that are typical of those expected in natural oceanic systems. The results of the 2D study indicate that although the dissociation radius remains rather limited even after long-term production, low intrinsic permeability and/or high hydrate saturation can lead to the evolution of high pressures that can threaten the formation and its boundaries with fracturing. Although lower maximum pressures are observed in the absence of bottom confining layers and in deeper (and thus warmer and more pressurized) systems, the reduction is limited. Wellbore designs with gravel packs that allow gas venting and pressure relief result in substantially lower pressures.

Introduction

Background. Gas hydrates are solid crystalline compounds in which gas molecules (referred to as guests) are lodged within the lattices of ice crystals (called hosts). Under suitable conditions of low temperature and high pressure, a gas G will react with water to form hydrates according to

$$G + N_H\,H_2O = G{\bullet}N_H\,H_2O,$$

where N_H is the hydration number. Of particular interest are hydrates formed by hydrocarbon gases when G is an alkane. Natural hydrates in geological systems also include CO_2, H_2S and N_2 as guests. Vast amounts of hydrocarbons are trapped in hydrate deposits[1]. Such deposits occur in two distinctly different geologic settings where the necessary low temperatures and high pressures exist for their formation and stability: in the permafrost and in deep ocean sediments.

The three main methods of hydrate dissociation are[1]: (1) depressurization, in which the pressure P is lowered to a level lower than the hydration pressure P_e at the prevailing temperature T, (2) thermal stimulation, in which T is raised above the hydration temperature T_e at the prevailing P, and (3) the use of inhibitors (such as salts and alcohols), which causes a shift in the P_e-T_e equilibrium through competition with the hydrate for guest and host molecules. Dissociation results in the production of gas and water, with a commensurate reduction in the saturation of the solid hydrate phase.

Gas hydrates exist in many configurations below the sea floor, including massive (thick solid zones), continuous layers, nodular, and disseminated, each of which may affect the seafloor stability differently. The hydrates in all of these configurations may be part of the solid skeleton that supports overlying sediments, which ultimately support platforms and pipelines needed for production from conventional oil and gas resources, and from hydrate accumulations (when it becomes economically and technically viable).

Objective and Problem Description. The main objective of this study is to evaluate the response of marine Hydrate-Bearing Sediments (hereafter referred to as HBS) to thermal loading. Such thermal loading occurs when heat from hot reservoir fluids (produced from deeper reservoirs) flows into the HBS through uninsulated pipes.

The resulting rise in temperature in the HBS can have serious consequences. Even before dissociation is attained, a rising temperature T is expected to affect the mechanical strength of hydrate-bearing sediments – possibly severely, given the narrow temperature range between hydrate stability and dissociation. When the temperature T reaches the hydrate equilibrium T_e temperature (see Figure 1) at the prevailing pressure P