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Numerical studies of methane production from Class 1 gas hydrate accumulations enhanced with carbon dioxide injection

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ABSTRACT

Class 1 gas hydrate accumulations are characterized by a permeable hydrate-bearing interval overlying a permeable interval with mobile gas, sandwiched between two impermeable intervals. Depressurization-induced dissociation is currently the favored technology for producing gas from Class 1 gas hydrate accumulations. The depressurization production technology requires heat transfer from the surrounding environment to sustain dissociation as the temperature drops toward the hydrate equilibrium point and leaves the reservoir void of gas hydrate. Production of gas hydrate accumulations by exchanging carbon dioxide with methane in the clathrate structure has been demonstrated in laboratory experiments and proposed as a field-scale technology. The carbon dioxide exchange technology has the potential for yielding higher production rates and mechanically stabilizing the reservoir by maintaining hydrate saturations. We used numerical simulation to investigate the advantages and disadvantages of using carbon dioxide injection to enhance the production of methane from Class 1 gas hydrate accumulations. Numerical simulations in this study were primarily concerned with the mechanisms and approaches of carbon dioxide injection to investigate whether methane production could be enhanced through this approach. To avoid excessive simulation execution times, a five-spot well pattern with a 500-m well spacing was approximated using a two-dimensional domain having well boundaries on the vertical sides and impermeable boundaries on the horizontal sides. Impermeable over- and under burden were included to account for heat transfer into the production interval. Simulation results indicate that low injection pressures can be used to reduce secondary hydrate formation and that direct contact of injected carbon dioxide with the methane hydrate present in the formation is limited due to bypass through the higher permeability gas zone.

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1. Introduction

The conventional concept behind producing natural gas from geologic accumulations of gas hydrates is to somehow alter the reservoir environment from being thermodynamically stable to unstable for methane hydrates. Thermodynamic stability of gas hydrates depends on temperature, pressure of guest molecules, and aqueous solute concentrations. Approaches for producing gas hydrates have focused on elevating the reservoir environment temperature (thermal stimulation), lowering the system pressure (depressurization), or raising the aqueous solute concentration (inhibitor injection). These more conventional approaches shift the environment to one that is thermodynamically unstable for methane hydrates, resulting in dissociation of the gas hydrate and liberation of natural gas. An alternative approach is to lower the partial pressure of the guest molecule by introducing a substitute guest molecule. Methane (CH_4) and carbon dioxide (CO_2) both form structure I hydrates (Sloan and Koh, 2007). Introducing carbon dioxide into geologic media filled with methane hydrate results in the displacement of methane with carbon dioxide as the guest molecule, without the dissociation of the gas hydrate (Stevens et al., 2008; Graue et al., 2006).

1.1. Carbon dioxide and methane exchange

The concept of exchanging carbon dioxide with methane in geologic accumulations of natural gas hydrates as a production technology was first advanced by Ohgaki et al. (1996). This concept

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was then extended to ethane hydrates by Nakano et al. (1998). The original concept proposed by Ohgaki et al. (1996) involved injecting carbon dioxide gas into an aqueous-gas-hydrate system and allowing the carbon dioxide and methane to equilibrate. The greater chemical affinity for carbon dioxide over methane in the hydrate structure, as evidenced by the higher heat of formation and equilibrium temperature, yields a mixed carbon dioxide-methane hydrate. Resulting equilibrium concentrations of carbon dioxide are greater than methane in the hydrate phase and less than methane in the gas phase. Since the original studies by Ohgaki et al. (1996), Hirohama et al. (1996), and Komai et al. (1997), the carbon dioxide-methane exchange technology has been investigated by others. Smith et al. (2001) assessed the feasibility of exchanging carbon dioxide with methane in geologic accumulations of gas hydrate by examining the thermodynamic potential for the exchange as a function of pore sizes. This study concluded that the replacement of methane by carbon dioxide in geologic accumulations of gas hydrate is less thermodynamically favored as pore size decreases.

Following these laboratory investigations of guest-molecule exchange for gas hydrates in geologic media, several researchers explored concepts for developing field production technologies. Rice (2003, 2006) proposed a methane hydrate production scheme for suboceanic deposits that yields hydrogen and carbon dioxide. In this scheme, methane hydrate is produced using the more conventional technologies (e.g., thermal stimulation, depressurization) and the captured carbon dioxide is sequestered on the ocean floor or in the suboceanic sediments in hydrate form. Whereas Rice's scheme involves carbon dioxide sequestration in hydrate form, the carbon dioxide-methane molecular exchange is indirect, requiring hydrate dissociation and subsequent reformation. McGrail et al. (2004) proposed a concept for exchanging carbon dioxide with methane in geologic deposits of gas hydrate by injecting a microemulsion of liquid carbon dioxide and water. The microemulsion is designed to provide sensible heat to dissociate the methane hydrate, taking advantage of the higher heat of formation for the carbon dioxide hydrate versus the methane hydrate. This technology was demonstrated in laboratory columns and numerically simulated (White and McGrail, 2006). Castaldi et al. (2007) investigated the technical feasibility of a down-hole combustion method for producing natural gas hydrate and sequestering carbon dioxide. The details of replacing carbon dioxide with methane in the hydrate structure was left unspecified, other than requiring a balance in the rates of methane hydrate dissociation and carbon dioxide hydrate formation.

1.2. Alaska north slope resource potential

The U.S. Department of Energy (DOE) and British Petroleum Exploration Alaska, Inc. (BPXA) have been conducting a joint research project to explore and characterize the Alaska North Slope (ANS) gas hydrate accumulations with the perspective of developing this potential unconventional energy resource (Hunter et al., 2011). USGS estimates a mean value of 16.7 trillion cubic meters (TCM) of natural gas in gas hydrate accumulations on the ANS, of which 0.93 TCM were estimated to occur within the shallow sand reservoirs beneath the ANS production infrastructure within the Eileen trend (Collett, 1995). The Eileen and Tarn trends are gas hydrate accumulations beneath the petroleum industry infrastructure within the Milne Point Unit (MPU), Prudhoe Bay Unit (PBU), and Kuparuk River Unit (Collett, 1993). A key component of this gas hydrate resource assessment project was the drilling of and data acquisition from the BPXA-DOE-USGS Mount Elbert Gas Hydrate Stratigraphic Test Well (the Mount Elbert Well), completed in February 2007, and the subsequent numerical simulation of the pumping experiments conducted with the Modular Dynamics Testing (MDT) downhole tool (Anderson et al., 2011). These simulations were conducted as part of the DOE sponsored international code comparison activities for gas hydrate simulators (Wilder et al., 2008).

Gas hydrate saturation logs from the Mount Elbert well, based on combinable magnetic resonance data, indicate two gas-hydrate bearing sands of 7.9–22.9 m thick. Both the upper zone (D) and lower zone (C) show variable gas-hydrate saturations, reaching maximum values of 0.75 with the remaining pore space being filled with water. Fig. 1 shows hydrate saturation and thickness maps of the D and C

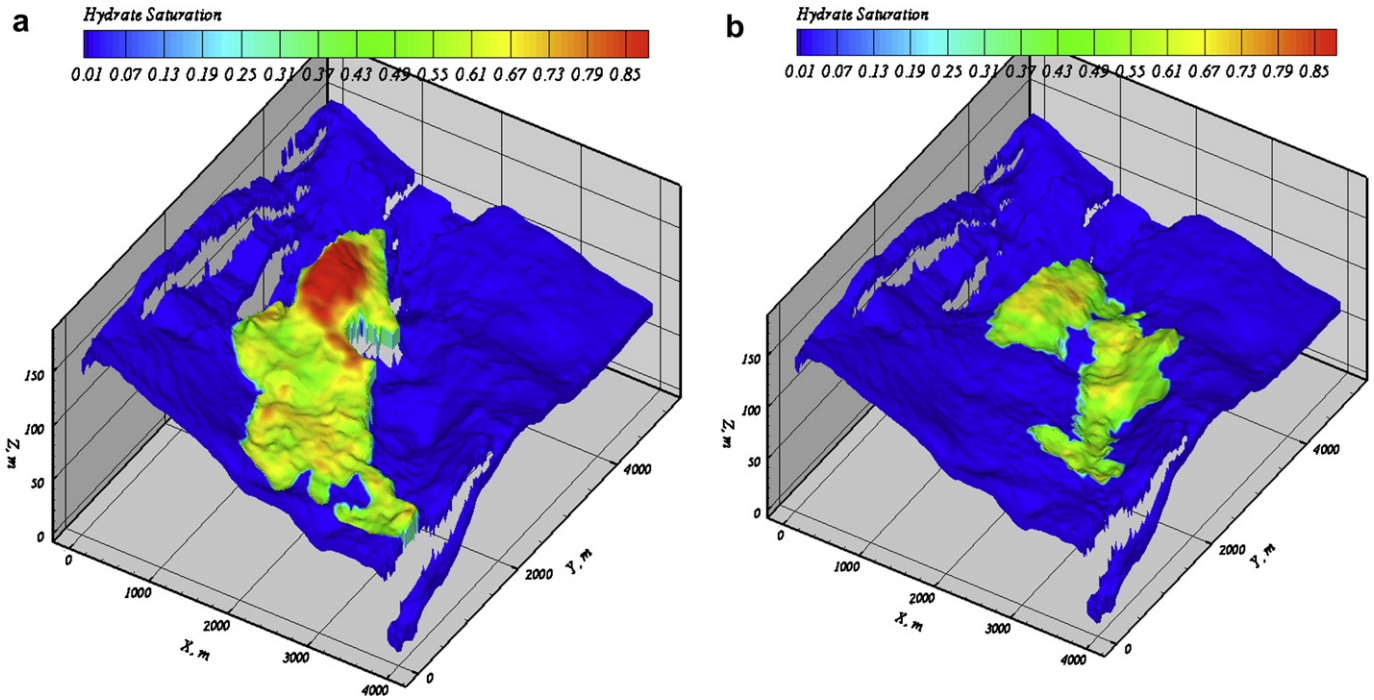

Fig. 1. Gas hydrate saturation and thickness map of the unit D (right) and C (left) gas-hydrate bearing sands. Faults are shown as map offsets (Lee et al., 2011).

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