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Analysis of heat transfer influences on gas production from methane hydrates using a combined method

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ABSTRACT

Heat transfer affects the pressure and temperature distributions of hydrate sediments, thereby controlling hydrate dissociation. Therefore, its study is essential for planning hydrate exploitation. Previously, a two-dimensional axisymmetric model, to investigate the influence of heat transfer on hydrate exploitation from hydrate-bearing sediments, was developed and verified. Here, we extended our investigation to the influence of heat transfer on methane gas production using a combined method coupling depressurization and thermal stimulation. Our simulations showed that during decomposition by the combined method, a high specific heat capacity of the hydrate-bearing porous media or a high initial water content could inhibit gas generation. However, the initial water content had only a weak influence on the cumulative gas production and generation rate. The influence of water and methane heat convection was also weak. An increase of the thermal conductivity initially inhibited hydrate dissociation but later promoted it. The implementation of the combined method increased gas generation compared with using only thermal stimulation. However, the benefits gradually diminished with an increasing heat injection temperature.

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1. Introduction

Worldwide, a large volume of hydrates can be found beneath the sea and in permafrost sediments [1]. Considering their potential as energy resources, the development of safe and efficient methods for gas extraction from gas hydrate sediments has become a widespread aim. At present, different methods for exploitation have been proposed, typically based on the disruption of thermodynamic equilibrium by depressurization [2–5], thermal stimulation [6–8], or a combined method [9,10].

For a safe and effective exploitation of hydrates and to avoid the limitations and disadvantages of a single approach, methods combining multiple techniques have recently been developed. Liu et al. [11] developed a one-dimensional mathematical model to predict hydrate decomposition in hydrate sediments via depressurization and thermal stimulation. Their simulations showed that thermal stimulation at constant temperature plays a limited role in hydrate exploitation compared with depressurization. Li et al. [12] conducted an experimental study to investigate whether the combination of thermal stimulation and depressurization was propitious to natural gas hydrate dissociation and their results suggested that such combination could achieve a higher energy efficiency. Bai and Li [13] used physical and mathematical models based on this combined method to analyze how gas and water production were influenced by multiphase fluid flow, kinetic and endothermic processes during decomposition, and heat convection and conduction. Their simulations showed that, under certain conditions, the combined method provided a longer and more stable period of high gas extraction rates over the single method. Feng et al. [14–16] used a one-dimensional system for depressurization and thermal stimulation experimental studies. To date, studies typically indicated that the combined method is more advantageous for hydrate exploitation than a single production method. However, few studies analyzed the effect of heat transfer.

Heat transfer affects the pressure and temperature distributions in hydrate sediments, thereby controlling hydrate decomposition [1]. This study extends our previous investigation [17,18] to address the influence of heat transfer on hydrate exploitation using the combined method. We focused on the various heat transfer modes that affect the gas generation rate and cumulative production, including the sensible heat, conductive heat flow, and convective heat transfer.

2. Modeling methodology

The mathematical models and assumptions made in this study were based on our previous work [17–21]. Three components (gas,

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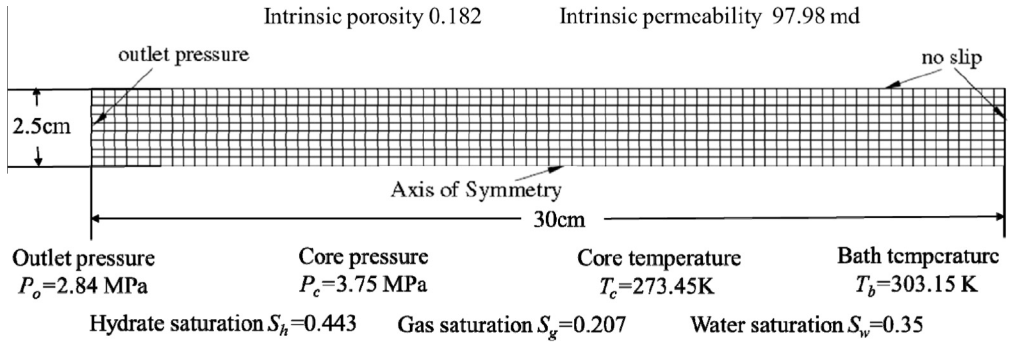

Fig. 1. Scheme of the computational hydrate core sample adapted from previous work [17–21].

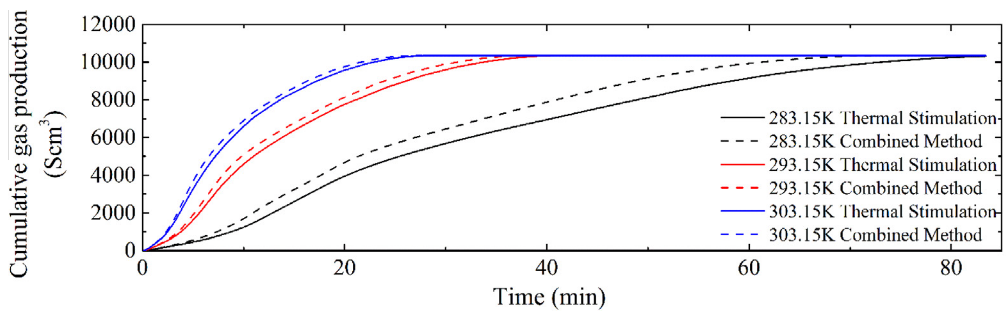

Fig. 2. Cumulative gas production over time for different stimulation temperatures. The thermal stimulation and combined methods were compared for different temperatures.

water, and hydrate) and three phases (gas, liquid, and solid) were represented in the models. Equations for the mass conservation, energy conversion, reaction kinetics, motion, and state of the three components were used to simulate hydrate dissociation from hydrate reservoirs. In the model, the core was immersed in a water bath, with an outlet valve located on the left side of the core. The walls and the right side of the core were considered no-slip boundaries (Fig. 1). Free convection heat transfer was assumed between the circular wall and the surroundings. Adiabatic boundary conditions were imposed at the ends of the core. These conditions were

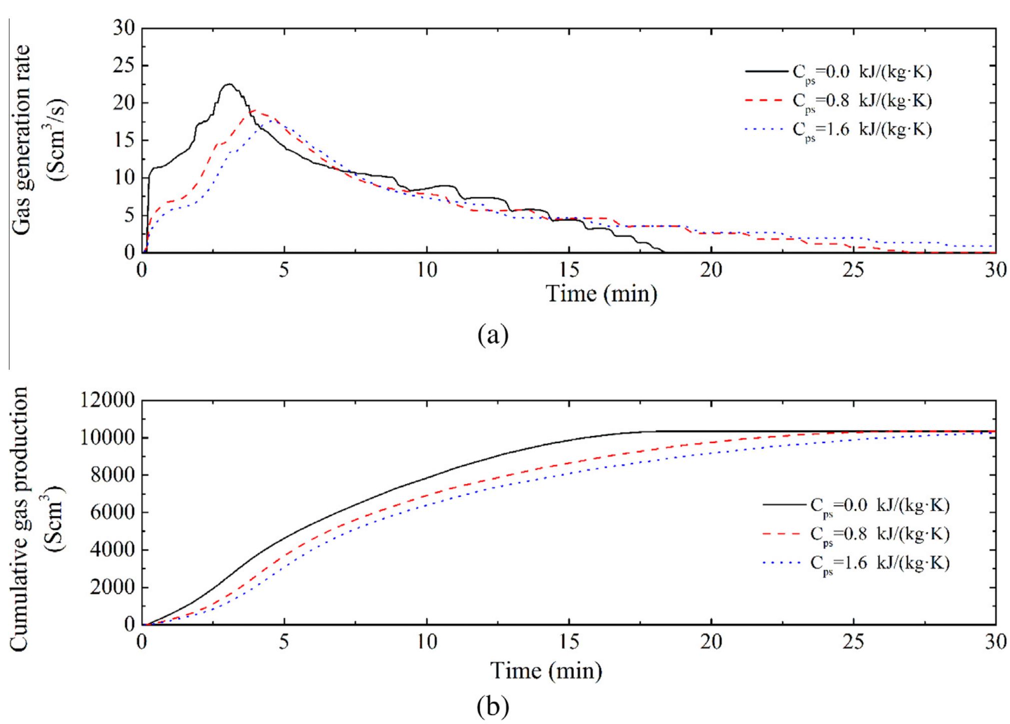

Fig. 3. (a) Gas generation rate and (b) cumulative gas production over time for different core specific heat capacities (C_{ps}): 0, 0.8, and 1.6 kJ/(kg K).

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