

Experimental and Numerical Studies on Dissociation of Methane Hydrate by Simultaneous Injection of Nitrogen and Hot Water

Yasuhide Sakamoto

Institute for Geo-Resources and Environment, National Institute of Advanced Industrial, Science and Technology (AIST), Tsukuba, Ibaraki, Japan

Yusuke Nakano, Fuyuki Kaneko, Kengo Nakamura and Takeshi Komai
Graduate School of Environmental Studies, Tohoku University
Sendai, Miyagi, Japan

This study aims to investigate the targeting behavior of a gas phase consisting of multicomponent and gas-water multi-phase flow assumed in an in situ low-temperature oxidation (LTO) process as an enhanced gas recovery from a methane hydrate (MH) reservoir. Experimental and numerical studies on MH dissociation in porous media by simultaneous injection of N₂ and hot water were carried out. It can be confirmed based on experimental results that the equilibrium temperature as a result of the decrease of the molar fraction of methane gas (CH₄) in the gas phase with N₂ injection was maintained at a lower level so that dissociated CH₄ production was completed earlier. In addition, based on the experimental observation of change of equilibrium temperature, the interfacial model of MH for the estimation of fugacity change was constructed and introduced into the numerical model. The history matching for temperature change, permeability characteristics, and CH₄ production during simultaneous injection process was subsequently conducted. Through the optimization of each parameter, it was found that the calculated results could reproduce a series of behaviors quantitatively. As a result, from the viewpoint of the behavior of the gas phase consisting of multicomponents on MH dissociation, the validity of a numerical model developed for an in situ LTO process has been confirmed.

NOMENCLATURE

A_{HS}	Surface area of spherical MH grain (1/ μm) (= 0.375)
D_{gc,CH_4}	Dispersion coefficient of CH ₄ in a gas phase (m ² /s)
D_{gc,N_2}	Dispersion coefficient of N ₂ in a gas phase (m ² /s)
E_d	Activation energy (J/mol) (= 9,400)
K_g	Comprehensive rate constant of MH growth (1/(m·MPa·s))
k_{d0}	The intrinsic dissociation rate constant (kmol/(m ² ·MPa·s))
o	The reaction order of water saturation for MH growth (dimensionless)
p	The reaction order of the average sand grain diameter for MH growth (dimensionless)
q	The reaction order of fugacity difference for MH growth (dimensionless)
q_{gi}	Gas injection rate (m ³ /s)
q_{gp}	Gas production rate (m ³ /s)
R	Gas constant (J/(K·kmol)) (= 8.31 × 10 ³)
S_g	Gas saturation (dimensionless)
t	Time (s)
μ_g	Viscosity of the gas phase (Pa·s)
ρ_g	Mole weight of gas (kmol/m ³)
ρ_{gi}	Mole weight of injected gas (kmol/m ³)
ρ_{gp}	Mole weight of produced gas (kmol/m ³)
Φ_g	Flow potential of gas phase (Pa)

INTRODUCTION

Methane hydrate (MH) existing in marine sediments close to Japan is expected to be developed as an energy resource for the country in the future (Okuda, 1993; Sato, 2001; Sato and Aoki, 2001). To recover methane gas (CH₄) from MH sediments, depressurization is regarded as the most effective process from the viewpoint of productivity and economic efficiency (Yamamoto, 2009). The methane hydrate offshore production test by depressurization has been conducted twice, in 2013 and in 2017, on the MH sediment near Japan, and gas production through this process has been demonstrated and reported (MH21 Research Consortium, 2013, 2017; Ministry of Economy, Trade and Industry, 2017). However, because MH dissociation is an endothermic reaction, the dissociation stagnation may occur as a result of decreases in temperature as the dissociation by depressurization progresses; as a result, total gas recovery through the application of depressurization as a primary recovery process is estimated at 40%–50% (Kurihara et al., 2009). Therefore, to further promote dissociation and enhance gas production, supplying additional heat to the MH reservoir is very important, and several gas production methods, based on experimental and numerical studies, have been proposed as secondary recovery processes after the depressurization (Zhou et al., 2008; Deusner et al., 2012; Konno et al., 2012, 2014; Minagawa et al., 2015).

In our previous paper, we proposed a new in situ low-temperature oxidation (LTO) process as a secondary recovery process to improve the energy efficiency in conventional hot water injection (Sakamoto et al., 2020). An illustration for this in situ LTO process is shown in Fig. 1. It is based on the concept that an LTO reaction of an injected organic substance (IOS) results in the formation of a hot water zone under an in situ reservoir condition. The numerical model had been developed targeting this process by considering a series of physical phenomena shown in Fig. 1, and numerical studies were performed to clarify the behavior of

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