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Numerical Study on the Application of In situ Low-temperature Oxidation for Enhanced Recovery from Methane Hydrate Reservoir

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In this study, a new in situ low-temperature oxidation (LTO) process was developed under the concept of effective utilization of heat generation, resulting from LTO of the injected organic substance (IOS), for the promotion of in situ dissociation of methane hydrate (MH) and the enhancement of gas recovery. When water containing the IOS component and air as an oxidant are injected into the MH reservoir, a high-temperature zone by heat generation is formed under the in situ condition. From this process, in addition to MH dissociation, a numerical model considering multicomponent flow in porous media with LTO reaction was constructed. From the calculation results, it was found that the high-temperature zone formed as a result of heat generation extended to the side of the production well, which promoted MH dissociation. In addition, gas recovery as high as 80% to 100% could be obtained through depressurization and in situ LTO process.

NOMENCLATURE

A_{HS}	Surface area of spherical MH grain (1/μm)
D_A	Average grain diameter (m)
$D_{gc,m}$	Dispersion coefficient of each gas component ($m = 1, 4$) (m^2/s)
D_{wc}	Dispersion coefficient of IOS component (m^2/s)
E_d	Activation energy (J/mol) (=9,400)
K	Absolute permeability under MH existence (m^2)
K_g	Comprehensive rate constant of MH growth (1/(m·MPa·s))
k_{d0}	Intrinsic dissociation rate constant (kmol/(m^2·MPa·s))
k_{rg}	Relative permeability to gas (dimensionless)
k_{rw}	Relative permeability to water (dimensionless)
o	The reaction order of water saturation for MH growth (dimensionless)
p	The reaction order of average sand grain diameter for MH growth (dimensionless)
q	The reaction order of fugacity difference for MH growth (dimensionless)
R	Gas constant (J/(K·kmol))
S_g	Gas saturation (dimensionless)
S_h	Hydrate saturation (dimensionless)
S_{wi}	Irreducible water saturation (dimensionless)
t	Time (s)
$w_{gci,m}$	Injected mole fraction of each component in gas phase ($m = 1, 4$) (dimensionless)
$w_{gcp,m}$	Produced mole fraction of each component in gas phase ($m = 1, 4$) (dimensionless)
$x_{os,i}$	Injected concentration of IOS component (dimensionless)
$x_{os,p}$	Produced concentration of IOS component (dimensionless)
μ_g	Viscosity of gas phase (Pa·s)
μ_w	Viscosity of water phase (Pa·s)
ρ_g	Mole weight of gas phase (kmol/m^3)
ρ_h	Mole weight of MH phase (kmol/m^3)
ρ_i	Mole weight of ice phase (kmol/m^3)
Φ_g	Flow potential of gas phase (Pa)
Φ_w	Flow potential of water phase (Pa)

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KEY WORDS: Methane hydrate, dissociation, low-temperature oxidation, in situ heat generation, enhanced gas recovery, simulation.

INTRODUCTION

Methane hydrate (MH) existing in marine sediments near Japan is expected to be developed as a domestic energy resource in the future (Okuda, 1993; Sato, 2001; Sato and Aoki, 2001). As a gas recovery method for an MH reservoir, the depressurization process is regarded as the most effective process from the aspect of gas productivity and economic efficiency (Yamamoto, 2009). In March 2013 and May 2017, the methane hydrate offshore production test applying depressurization was conducted, and a continuous methane gas production was confirmed (MH21 Research Consortium, 2013; Ministry of Economy, Trade and Industry, 2017). However, because MH dissociation is an endothermic reaction, continuous dissociation by depressurization strongly depends on the sensible heat of the solid matrix and the heat conduction from the surrounding layers. As a result, if the reservoir temperature decreases as MH dissociation progresses, the stagnation of dissociation may result. The total gas recovery when depressurization is applied as a primary gas recovery process is generally estimated to be 40% to 50% (Kurihara et al., 2009). Therefore, it is particularly important to develop a secondary gas recovery process after the depressurization operation, by an additional heat supply into the reservoir in order to promote further MH dissociation.

For this purpose, several gas production methods as a secondary gas recovery process from the MH reservoir have been proposed in recent studies. For example, the utilization of latent heat obtained from ice formation by increasing the degree of depressurization to reach below the ice melting point (Konno et al., 2012, 2014), electrical heating via application of a voltage between wells (Minagawa et al., 2015), and the application