

Numerical Simulation of a Laboratory-scale Experiment for the Hydrate Dissociation Process in Porous Media by Acid Injection

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In this study, to enhance gas recovery from a methane hydrate reservoir, experimental and numerical studies that considered the acid injection process as a secondary gas recovery process after the depressurization operation were conducted. First, we experimentally analyzed the dissociation behavior of propane hydrate (PGH) in porous media by using acid injection and confirmed that the dissociation condition of PGH was shifted to the sides of low temperature and high pressure. This enabled the dissociation to proceed easily as the concentration of the injected acid increased. Then, on the basis of experimental observation, we conducted history matching for the temperature change and gas production behavior during PGH dissociation by acid injection, by varying the initial hydrate saturation, the reaction rate constant for acid consumption, and the intrinsic dissociation rate constant as the calculation parameters. Through history matching, we confirmed the validity of the developed numerical model targeting the dissociation of hydrates in porous media by acid injection.

NOMENCLATURE

A_{HS}	Surface area of spherical MH grain ($1/\mu\text{m}$) ($=0.375$)	U_w	Internal energy of hydrate (J/kmol)
D_{acid}	Dispersion coefficient of acid component (m^2/s)	$x_{\text{acid},a,p}$	Produced acid concentration after mineral dissolution (dimensionless)
D_{mine}	Dispersion coefficient of dissolved mineral component (m^2/s)	$x_{\text{acid},b,i}$	Injected acid concentration before mineral dissolution (dimensionless)
E_d	Activation energy (J/mol) ($=9,400$)	$x_{\text{acid},b,p}$	Produced acid concentration before mineral dissolution (dimensionless)
H_d	Heat of dissociation (J/kmol)	$x_{\text{mine},p}$	Produced dissolved mineral concentration (dimensionless)
h_g	Enthalpy of gas phase (J/kmol)	μ_g	Viscosity of gas phase (Pa·s)
h_w	Enthalpy of water phase (J/kmol)	μ_w	Viscosity of water phase (Pa·s)
i	Stoichiometric coefficient for acid dissolution (dimensionless)	λ_c	Apparent thermal conductivity of reservoir (J/(K·s))
K	Absolute permeability (m^2)	ρ_g	Mole weight of gas (kmol/m^3)
k_{rg}	Relative permeability to gas (dimensionless)	ρ_h	Mole weight of hydrate (kmol/m^3)
k_{rw}	Relative permeability to water (dimensionless)	ρ_w	Mole weight of water (kmol/m^3)
q_{ei}	Energy injection rate ($\text{J}/(\text{m}^3 \cdot \text{s})$)	ρ_{wi}	Mole weight of injected water (kmol/m^3)
q_{ep}	Energy production rate ($\text{J}/(\text{m}^3 \cdot \text{s})$)	ρ_{wp}	Mole weight of produced water (kmol/m^3)
q_{wi}	Water injection rate (m^3/s)	Φ_g	Flow potential of gas phase (Pa)
q_{wp}	Water production rate (m^3/s)	Φ_w	Flow potential of water phase (Pa)
R_g	Growth rate of hydrate ($\text{kmol}/(\text{m}^3 \cdot \text{s})$)		
S_g	Gas saturation (dimensionless)		
S_w	Water saturation (dimensionless)		
T	Temperature (K)		
t	Time (s)		
U_g	Internal energy of gas (J/kmol)		
U_h	Internal energy of hydrate (J/kmol)		
U_r	Internal energy of rock (J/m^3)		

INTRODUCTION

Methane hydrate (MH), existing in marine sediments close to Japan, is expected to be developed as a domestic energy resource in the future (Okuda, 1993; Sato, 2001; Sato and Aoki, 2001). To recover methane gas from MH sediments, depressurization is regarded as the most effective process from the viewpoints of productivity and economic efficiency (Yamamoto, 2009). The methane hydrate offshore production test by depressurization has been conducted twice, once in 2013 and again in 2017, on the MH sediment near Japan, and the demonstration of gas production through this process has been reported (MH21 Research Consortium, 2013, 2017; Ministry of Economy, Trade and Industry, 2017). On the other hand, MH dissociation is an endothermic reaction, and a decrease in reservoir temperature, as a result of

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KEY WORDS: Methane hydrate, propane hydrate, dissociation, acid injection, porous media, numerical simulation, history matching.