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Numerical Study on Enhanced Gas Recovery from Methane Hydrate Reservoir During In-situ Heating Process by Acid Injection

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In this study, under the concept of effective utilization of heat generation resulting from mineral dissolution via acid injection for the promotion of in-situ dissociation of methane hydrate (MH) and the enhancement of gas recovery, we conducted a series of numerical analyses of the acid injection process as a secondary gas recovery from an MH reservoir after the depressurization operation. For the numerical analysis, based on the assumption that the charge balance in the injected acid solution after the contact with the solid matrix becomes neutral as a result of mineral dissolution into the water phase, two acid components before and after the contact with the solid matrix were defined. In addition, the kinetic parameters and heat of mineral dissolution during the acid injection were obtained through laboratory column tests and differential scanning calorimetry (DSC) analysis, respectively, and introduced into the developed numerical model. From the calculation results, it was found that the high-temperature zone formed because of heat generation resulting from mineral dissolution extended to the side of the production well promoting MH dissociation, and the total gas recovery through depressurization and acid injection was estimated at approximately 90%.

NOMENCLATURE

A_{HS}: Surface area of spherical MH grain [1/μm] (= 0.375)
D_A: Average grain diameter [meters]
D_{acid}: Dispersion coefficient of acid component [m^2/s]
D_{mine}: Dispersion coefficient of dissolved mineral component [m^2/s]
E_d: Activation energy [J/mol] (=9,400)
i: The stoichiometric coefficient for acid dissolution [dimensionless]
K_g: Comprehensive rate constant of MH growth [1/(m·MPa·s)]
k_{d0}: Intrinsic dissociation rate constant [kmol/(m^2·MPa·s)] (=1.24×10^{11})
k_{rw}: Relative permeability to water [dimensionless]
n: Previous time level
$n+1$: Current time level
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 the fugacity difference for MH growth [dimensionless]
q_{wi}: Water injection rate [m^3/s]
q_{wp}: Water production rate [m^3/s]
R: Gas constant [J/(K·kmol)] (=8.31×10^3)
S_g: Gas saturation [dimensionless]
S_h: Hydrate saturation [dimensionless]
S_w: Water saturation [dimensionless]
t: Time [seconds]
$x_{\text{acid},a,p}$: Produced acid concentration after mineral dissolution [dimensionless]
$x_{\text{acid},b,i}$: Injected acid concentration before mineral dissolution [dimensionless]
$x_{\text{acid},b,p}$: Produced acid concentration before mineral dissolution [dimensionless]
$x_{\text{mine},p}$: Produced dissolved mineral concentration [dimensionless]
μ_w: Viscosity of water phase [Pa·s]
ρ_{wi}: Mole weight of injected water [kmol/m^3]
ρ_{wp}: Mole weight of produced water [kmol/m^3]
Φ_w: Flow potential of water phase [pascals]

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, depressurization that decreases the pore pressure by pumping water from a production well to promote in-situ MH dissociation is regarded as the most effective process from the viewpoint of gas productivity and economic efficiency (Yamamoto, 2009). In March 2013, the first methane hydrate offshore production test applying depressurization at the offing from the Atsumi Peninsula–Shima Peninsula was conducted, and a continuous methane gas production over six days at a production rate of approximately 20,000 Sm^3/day was reported (MH21 Research Consortium, 2013). Furthermore, for the purpose of more economical and stable long-term gas production via depressurization, a second offshore production test was conducted from May 2017, and continuous gas production over 20 days in total at a production rate of about 10,000 Sm^3/day has been confirmed (MH21 Research Consortium, 2017; Ministry of Economy, Trade and Industry, 2017).

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KEY WORDS: Methane hydrate, dissociation, acid injection, in-situ heat generation, enhanced gas recovery, simulation.