

# Modification of Permeability Model and History Matching of Laboratory-scale Experiment for Dissociation Process of Methane Hydrate: Part 2—Numerical Study for Estimation of Permeability in Methane Hydrate Reservoir

Yasuhide Sakamoto, Takeshi Komai, Taro Kawamura, Hideki Minagawa,  
Norio Tenma and Tsutomu Yamaguchi

Methane Hydrate Research Laboratory, National Institute of Advanced Industrial Science and  
Technology (AIST), Tsukuba, Ibaraki, Japan

**In this study, for the purpose of history matching a laboratory-scale experiment dissociation of methane hydrate (MH) by hot-water injection, we introduced the MH growth rate into the simulator and modified the numerical model. In addition, we extended the MH phase in the numerical model to a 2-component system by modeling the pore space occupied by MH. Absolute permeability was formulated for an MH 2-component system, and the relative permeability model was also modified as a function of sand grain diam and temperature in addition to MH saturation. As a result, the calculated temperature distribution and gas production behavior during MH dissociation sufficiently agreed with the experimental results. Further, it was found that this developed simulator could reproduce permeability characteristics, associated with both MH formation and dissociation.**

## INTRODUCTION

Methane hydrate (MH) is an ice-like solid substance in which the water molecule structure contains embedded methane molecules under low-temperature and high-pressure conditions. When 1 m<sup>3</sup> of MH is decomposed, approximately 150 m<sup>3</sup> of methane gas is produced. MH is one of the potential sources of natural gas, because a large number of reservoirs exists in marine sediments or in permafrost regions worldwide (Makogon, 1988; Okuda, 1993; Sato et al., 2001a, b). Some methods of MH extraction from the reservoirs have been proposed, such as depressurization, thermal stimulation and inhibitor injection (Makogon, 1981). These are all based on the in situ dissociation process of MH that is transformed into methane gas and water. Only methane gas can be produced from the reservoirs. It is supposed that this process consists of the following complicated physical phenomena.

1. The porosity and permeability of porous media change as a result of MH dissociation.

2. Dissociated gas and water migrate through pore space, which is formed by the extinction of MH crystals that function as a binder between sand grains.

3. The reservoir temperatures are changed by the generation of heat and mass flows of gas and water due to MH dissociation.

To evaluate the productivity of methane gas from the reservoirs, it is necessary to develop a gas production simulator and carry out parametric studies using the simulator. In particular, it is very important to estimate the permeability characteristics in an MH reservoir in situations such as dissociation and consolidation.

In our previous paper (Sakamoto et al., 2004a, 2006), to clarify the above physical phenomena extraction such as temperature change, permeability change, and gas production behavior during MH dissociation, we carried out an experimental study on the hot-water injection process as a thermal stimulation method

to extract methane gas from an MH reservoir. On the basis of the experimental results, we constructed a numerical model for the MH dissociation process to develop a gas production simulator. In addition, absolute permeability and relative permeability with MH formation were formulated as functions of MH saturation. On the basis of the following experimental condition, we carried out a simulation run, and compared the simulation results with the experimental results for temperature distribution, differential pressure and cumulative gas production.

Absolute permeability, m <sup>2</sup>	27.2 × 10 <sup>-12</sup>
Porosity	0.397
Reservoir pressure, MPa	7.50
Initial reservoir temperature, °C	3.70
Initial MH saturation	0.289
Initial gas saturation	0.611
Initial water saturation	0.000
Water injection rate, cm <sup>3</sup> /min	10.0
Temperature of injected water, °C	21.3

Fig. 1 shows a comparison of the experimental and calculation results for temperature distribution during the MH dissociation process by hot-water injection. The calculation results reproduced the temperature change observed in this experiment generally. However, between the experimental and calculation results, the difference in the time required to attain equilibrium temperature of MH at the initial stage was recognized. The time required to attain equilibrium temperature at 473 mm from the injection end of the sand column was 120 min in the calculation, so this value was almost twice that of the experiment. In the experiment, the time at which temperature reached equilibrium corresponded to the time when the front of the injected water reached each position in the sand column. We then supposed that MH re-formation and growth were promoted at each position and temperature rapidly increased to the equilibrium temperature. The movement speed of the MH dissociation front in the calculation was higher than the experimental result, because the effect of MH re-formation and growth had not been considered in the numerical model.

Fig. 2 shows the changes in differential pressure and cumulative gas production with time during the MH dissociation process; the

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