Laboratory-scale Experiment of Methane Hydrate Dissociation by Hot-water Injection and Numerical Analysis for Permeability Estimation in Reservoir: Part 1—Numerical Study for Estimation of Permeability in Methane Hydrate Reservoir

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We have carried out an experimental study on dissociation of methane hydrate (MH) by hot-water injection as a thermal stimulation method. On the basis of the experimental results, a numerical model of MH dissociation was designed to develop a gas production simulator. The numerical model consists of a 3-phase, 3-component system, such as gas, MH and water. As MH was not mobile due to its solid material, we defined the gas-water 2-phase flow with MH formation. Further, absolute permeability and relative permeability with MH formation were measured experimentally and formulated as functions of MH saturation. Using the developed simulator, we conducted history matching of laboratory-scale experiments for MH dissociation by hot-water injection.

INTRODUCTION

Methane hydrate (MH) is an ice-like solid substance in which a water molecule structure contains embedded methane molecules under low-temperature and high-pressure conditions. When 1 m³ of MH is decomposed, approximately 150 m³ of methane gas are produced. In the near future, MH will be a potential resource of natural gas, because of the vast amounts of reservoirs that exist in marine sediments and in permafrost regions worldwide (Makogon, 1988; Okuda, 1993; Sato et al., 2001a, b).

Some extraction methods of MH from reservoirs in marine sediments have been proposed, such as depressurization, thermal stimulation and inhibitor injection (Makogon, 1981). These are all based on the in-situ dissociation of MH that is transformed into methane gas and water. Only methane gas can be produced from the reservoirs in marine sediments. Fig. 1 shows the concept of MH extraction from marine sediments.

It is supposed that this process consists of the following complicated physical phenomena:

- The porosity and permeability of porous media are changed as a result of MH dissociation.
- 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.
- The reservoir temperatures are changed by the generation of heat and mass flows of gas and water due to MH dissociation.

It is very important to understand the physical phenomena in marine sediments with MH formation, particularly for developing the extraction system for MH, and for considering the environmental impacts due to the development.

Some numerical studies of MH dissociation in porous media have been reported. These studies are classified into:

- the analysis of the physical phenomena observed in laboratory-scale experiments, such as the movement of the MH dissociation front and the flow behavior of gas and water; and,
- field-scale simulation supposing the operation is in a real hydrate field.

Yousif et al. (1988) developed a 1-D simulator for depressurization in a Berea sandstone core, and conducted an analysis of the saturation distribution and production behavior of gas and water and the movement of the dissociation front. Selim et al. (1987) suggested a 1-D MH dissociation model for heat stimulation methods. They distinguished the analytical zone between the dissociated zone saturated with gas and water from the non-dissociated zone, and obtained some analytical solutions. Jeannin et al. (2002) investigated the dissolution of methane gas into the water phase, and treated the methane mole fraction in water as the driving force for dissociation in their simulation model. Holder et al. (1982) developed a 3-D simulator for depressurization intended for an MH reservoir located over a free gas layer. Masuda et al. have developed a multidisciplinary field-scale simulator, considering dissociation rate, endothermic reaction due to dissociation,

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**Fig. 1** Concept of gas hydrate extraction from marine sediments and developments of production simulator