International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 29, No. 1, March 2019, pp. 104–111; https://doi.org/10.17736/ijope.2019.jc739

http://www.isope.org/publications/publications.htm

Thermophysical Properties of Methane Hydrate-bearing Sediments Recovered from Nankai Trough Wells Under Vertical Stress Conditions

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This paper measures the thermophysical properties of natural methane hydrate (MH)-bearing sediments recovered from the Nankai Trough, Japan. The thermal conductivity, thermal diffusivity, and specific heat of the sample under vertical stress (VS) loading were measured by the hot-disk transient method. The thermal conductivity of the sediments increased with increasing VS. The specific heat and thermal diffusivity have a constant value independent of VS. After MH dissociation, the thermal conductivity and the specific heat dropped significantly, and the thermal diffusivity was increased. In addition, the thermal conductivity, specific heat, and thermal diffusivity were calculated by an estimation model.

INTRODUCTION

Methane hydrate (MH) is expected to be developed as an unconventional natural gas source, replacing existing fossil fuels. MH is a crystalline solid in which cages of hydrogen-bonded water molecules enclose the methane gas molecules. MH is stable in a high-pressure/low-temperature environment. A large amount of MH is known to exist in permafrost on land and in sedimentary layers beneath the seabed (Sloan and Koh, 2007).

The collected seismic data for oil and gas exploration show a wide distribution of bottom-simulating reflections (BSRs) under the seafloor in the Nankai Trough region near the Japan Sea coast. BSRs indicate the lower limit of gas hydrate stability zone in a vertical profile. In 1999, the first Nankai Trough methane hydrate exploration well was drilled. In early 2004, the Japan Ministry of Economy, Trade, and Industry drilled a multiwell from Tokai-oki to Kumano-nada (Tsuji et al., 2009). The core was recovered using a pressure-temperature core sampler, which maintained the in-situ condition of 16 excavation sites at water depths ranging from 720 to 2,030 m in the same year. Recovered core analysis confirmed that the MH-bearing sediments in the Nankai Trough area are pore-filling-type hydrates (Fujii, Nakamizu, et al., 2009; Fujii, Saeki, et al., 2009).

To prove that the depressurization method produces methane gas from MH-bearing sediments under the seafloor, the Japan Oil, Gas, and Metals National Corporation conducted a gas-production test in the Nankai Trough area in March 2013. The depressurization method lowers the bottom-hole pressure in the production well and reduces the pressure applied to the MH reservoir, promoting the dissociation of MH into gas and water. The produced methane gas is then recovered. Although the depressurization method is considered a viable option, some challenges must be overcome before adopting the method in practical mass production.

MH dissociation is an endothermic reaction, sourcing heat from the surrounding sediment. Therefore, in the depressurization method, the gas production rate and the recovery rate largely depend on the amount of heat supplied from the surrounding MH-bearing sediment and pore water. To model the effects of heat transfer on the hydrate dissociation process in porous media under depressurization, Zhao et al. (2014) developed and executed a two-dimensional axisymmetric simulator. They proposed that heat transfer governs the dissociation rate and affects the gas production. Konno et al. (2010) simulated an MH reservoir model of the Nankai Trough and suggested that depressurization-induced gas production from oceanic MH deposits requires a relatively high temperature of the MH-bearing sediment. Moridis et al. (2011) suggested that thermal conductivity and specific heat are important thermophysical properties. Yamamoto (2015) suggested that to develop MH as a resource and assess its economic value, we must understand the relevant heat and mass transport process in heterogeneous geological formations, the thermal and hydraulic characteristics of the reservoirs, and the relationships between these factors and geological features under in-situ conditions.

The thermophysical properties of MH-bearing sediments have been measured in both natural and artificial MH-bearing samples. Artificial hydrate-bearing sediments formed in the laboratory are suitable substitutes for natural hydrate-bearing sediments, which are difficult to obtain in their in-situ conditions. Waite et al. (2002) formed an artificial MH-bearing sediment by slowly heating granular H_2O ice in a pressurized CH_4 atmosphere. They reported that the intergranular contact growth of MH increases the heat transfer between the quartz and grains. The thermal conductivity of MH-bearing sediments consisting of natural sandy sediments and saline pore fluid was measured by Kim and Yun (2013). To control the degree of hydrate saturation in the core lab sediment samples, they employed the prewetting method followed by pore fluid injection. Their experiment was completed within a reasonable time frame. Other researchers have studied the environment of hydrate-bearing sediments under the sea floor by measuring the thermal conductivity of sediment under vertical stress (VS) conditions. Cortes et al. (2009) measured the thermal conductivities of sand and clay samples under various saturation conditions (air-dried, water- and tetrahydrofuran (THF)-saturated, and THF hydrate-saturated), varying the VS from 0.05 to 1 MPa. THF is often used as a guest molecule to ease the preparation of MH-bearing samples. Increasing the VS reduces the porosity of the sample, thereby increasing the thermal conductivity. Applying the hot-disk transient method, Li and Liang (2016) measured the thermal conductivities of artificial MH-bearing sand samples

Received January 11, 2018; revised manuscript received by the editors May 22, 2018. The original version was submitted directly to the Journal.

KEY WORDS: Thermophysical properties, natural methane hydrate-bearing sediment, vertical stress, sediment after hydrate dissociation, estimation model, hot-disk transient method, Nankai Trough well.