



Influence of core scale permeability on gas production from methane hydrate by thermal stimulation

Yongchen Song, Yangmin Kuang, Zhen Fan, Yuechao Zhao, Jiafei Zhao*

Key Laboratory of Ocean Energy Utilization and Energy Conservation of Ministry of Education, Dalian University of Technology, Dalian 116024, China

ARTICLE INFO

Article history:

Received 19 May 2017

Received in revised form 25 December 2017

Accepted 30 December 2017

Keywords:

Methane hydrate
Gas production
Permeability
Thermal stimulation
Numerical simulation

ABSTRACT

The hydrate dissociation process involves heat transfer in the decomposing zone, multi-phase fluid flow during gas production, and the intrinsic kinetics of hydrate dissociation. The potential impact of laboratory-scale permeability on hydrate exploitation from hydrate-bearing sediments was predicted from a previously developed and verified two-dimensional axisymmetric model. We herein continue the previous work to investigate the influence of core-scale hydrate sediments' permeability on gas production by the thermal stimulation method. The results show that the gas production in relatively low permeability reservoirs proceeded at a faster rate, requiring less time to complete the dissociation process, although an optimal permeability was associated with the fastest gas production. In addition, with the temperature continuously increased, the dissociation front displaced from the boundary wall to the core axis along the radial direction. In a lower permeability system, however, the hydrate dissociation process at the zone opposite the outlet valve was delayed. Due to the varying processes associated with hydrate dissociation, the overall thermal conductivity declined faster at an earlier stage in sediments of high permeability as compared with sediments of lower permeability. Furthermore, the effects of boundary heat transfer were more significant for low permeability systems.

© 2018 Elsevier Ltd. All rights reserved.

1. Introduction

The existence of natural gas hydrates was verified in the 1960s [1,2]. Gas hydrates are solid crystalline compounds in which gas molecules are encaged inside the lattices of ice crystals. Vast amounts of hydrocarbons are trapped in hydrate deposits [3]. Potential reserves of hydrated gas are estimated to exceed $1.5 \times 10^{16} \text{ m}^3$ and are distributed all over the Earth both on the seafloor (97%) and permafrost (3%) [4,5]. Given its wide distribution and energy-rich properties, researchers have developed three principal mining methods to acquire this environmentally friendly resource [6,7]. These methods include thermal stimulation [8–10], depressurization [11–15], and the combined method [16,17]. However, to optimize production efficiency, and avoid ice blockage and hydrate re-formation, the combination of depressurization and thermal stimulation is considered a profitable method for hydrate acquisition [16–20].

Over the past two decades, both numerical simulations and experiments have been performed for methane hydrate decomposition and gas production from the hydrate. Researchers have

found that the methane hydrate dissociation process involves heat transfer (convection, conduction and phase change), phase transitions (the intrinsic kinetics of hydrate dissociation), and gas/water permeation (multi-phase fluid flow) during gas production [21,22]. Heat transfer affects the pressure and temperature distributions in hydrate sediments, thereby controlling hydrate decomposition [16]. Accordingly, Zhao et al. [23–25] analyzed the heat transfer effects on gas production from methane hydrate using thermal stimulation, depressurization and the combined method. It was concluded that (a) the porous media material and associated water content are two significant factors that affect the sensible heat in gas hydrate dissociation, and (b) a high specific heat capacity of the hydrate-bearing porous media and the high initial water content could inhibit gas generation. Meanwhile, recently Chen et al. [26] also found that the dissociation on a core scale is more heat-transfer controlled by numerical modeling and experimental verification. Moridis et al. [27] tested methane hydrate dissociation by means of thermal stimulation in order to simulate kinetic hydrate decomposition in porous media. Tang et al. [21] concluded that the determining factor in core-scaled tests is the intrinsic kinetics of hydrate decomposition as compared to heat and mass transfer. Because the permeability of hydrate-bearing sediments affects fluid flow during the hydrate dissociation process, and given that multi-phase fluid flow affects heat transfer, permeability becomes

* Corresponding author.

E-mail addresses: songyc@dlut.edu.cn (Y. Song), jfzhao@dlut.edu.cn (J. Zhao).

Nomenclature

A	convective heat transfer area (m^2)	S_{gr}	gas residual saturation
α	convective heat transfer coefficient ($\text{J}/(\text{m}^2 \text{K})$)	S_{wr}	water residual saturation
K	permeability (mD)	T	temperature (K)
K_0	absolute permeability (mD)	$??$	axis distance (m)
K_r	relative permeability of gas or water (mD)		
N	permeability reduction factor, $N = 15$	Subscripts	
N_g	empirical constants in Eq. (4), $n_g = 2$	G	Gas phase
N_w	empirical constants in Eq. (4), $n_w = 4$	H	Hydrate phase
P	pressure (MPa)	In	Heat from convective heat transfer
\dot{q}	energy source (J)	S	Sediment phase
R	radial distance (m)	W	Water phase
S	saturation of phase		

a critical factor in gas production from hydrate reservoirs. Oyama et al. [22] investigated the dissociation of methane hydrate-bearing depressurized natural cores of low permeability. Results indicated that depressurization of a low permeability natural core differs from that of a high permeability artificial core because of the time delay required for the upstream pressure to reach production pressure. However, few numerical simulations have been performed to investigate hydrate dissociation in low-permeability sediments.

Previous investigations have addressed this deficiency analyzing the influence of reservoir permeability on methane hydrate dissociation induced by depressurization [28]. This work has been extended to ascertain the effects of reservoir permeability on methane hydrate dissociation by thermal stimulation. Therefore, this study examines the influence of pressure and temperature evolution, and of the distribution of hydrate saturation in the sediment, on gas production from the hydrate-bearing reservoir.

2. Mathematical model

The mathematical model and associated assumptions used in this study are based on previous work [23,29]. The model utilizes three components (gas, water, and hydrate) and three phases (gas, water, and solid). Equations governing the conservation of mass, energy conversion, reaction kinetics and motion – together with the equations of state of the three components – are used to simulate hydrate decomposition in porous media. In our model, the conditions are based on those described by Masuda et al. [30]. The hydrate core sample and computational grid employed in this study are shown in Fig. 1. The measuring point A is set in the center of the sediment core. The modeled core is immersed in a water bath, and the outlet valve is defined to the left side of the core. The walls and the right-hand side of the core are assumed as no-slip boundaries. Convective heat transfer occurs between the circular wall and the surrounding water bath, i.e., $q_{in} = \alpha \Delta T$, where α is

the convective heat transfer coefficient and ΔT is the temperature difference between the wall and the surrounding water bath [23]. Adiabatic boundary conditions define the right-hand end of the core. Initial conditions based on Masuda et al.'s experiments [30] are shown in Table 1 and described as follows:

$$T = T_0, \quad P = P_0, \quad S_h = S_{h0}, \quad S_w = S_{w0}, \quad S_g = S_{g0} \quad (0 \leq r \leq R, \quad 0 \leq x \leq L) \quad (1)$$

where T is the core temperature, P is the pressure, S_h is the hydrate saturation, S_w is the water saturation, and S_g is the gas saturation. R is the core radius, and L is the core length.

The following boundary conditions are applied to the simulation model:

$$P = P_{outlet}(x = 0), \quad \frac{\partial P}{\partial x} = 0(x = L), \quad \frac{\partial P}{\partial r} = 0(r = 0, R), \quad \frac{\partial T}{\partial r} = 0(r = 0), \quad \frac{\partial T}{\partial x} = 0(x = 0, L) \quad (2)$$

The absolute permeability of the hydrate-bearing sediments can be calculated as follows:

$$K = K_0(1 - S_h)^N \quad (3)$$

where K_0 represents the absolute permeability of the hydrate-free sediments and N denotes the permeability reduction index. In this study, the value of N is assumed to be 15 as recommended by Masuda et al. [30].

The relative permeability of water and gas are defined with Corey's model:

$$k_{rw} = \left(\frac{S_w - S_{wr}}{1 - S_{wr} - S_{gr}} \right)^{n_w}, \quad k_{rg} = \left(\frac{S_g - S_{gr}}{1 - S_{wr} - S_{gr}} \right)^{n_g} \quad (4)$$

where S_{wr} is the residual water saturation, S_{gr} is residual gas saturation, and n_w and n_g are empirical constants controlling the values of

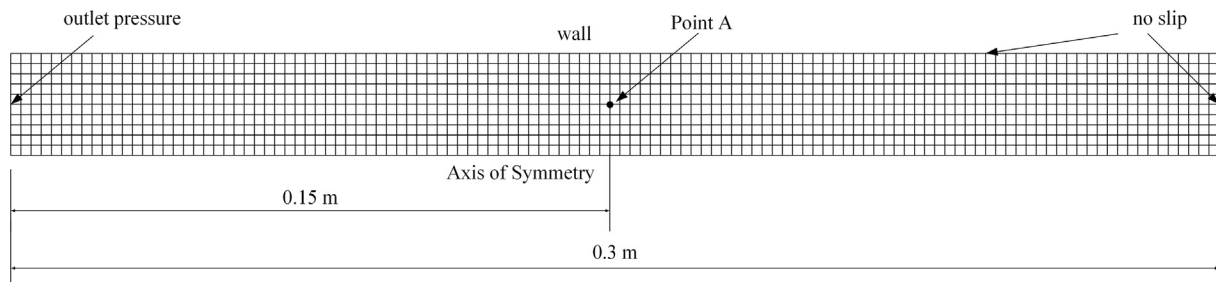


Fig. 1. Schematic of hydrate core sample and the computational grid.

Download English Version:

<https://daneshyari.com/en/article/7054448>

Download Persian Version:

<https://daneshyari.com/article/7054448>

[Daneshyari.com](https://daneshyari.com)