

A Mathematical Model for Dissociation of Gas Hydrate

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ABSTRACT

This paper presents a model for natural gas hydrate dissociation from the methane hydrate reservoir by depressurization or temperature-falling of the well. In this model, the controlling equations are consisted of quality conservation, momentum equilibrium and energy conservation equations. Four media: Free methane (gas), methane hydrate (solid), rock skeleton, and water (liquid) are in thermodynamic equilibrium. The heat suction by the dissociation and the convection-conduction are considered also. The geological formation is assumed to be uniform and the flow of free methane is regarded as flow through a porous media with porosity. It is shown that the dissociation rate increases with the increase of depressurization and the increase of initial saturation of gas hydrate and degrades fast with the distance from the boundary. The changes of the pressure on the boundary have large effects on the dissipation of the pore pressure. The changes of the heat conductivity have little effects on the dissociation of gas hydrate and the dissipation of pore pressure.

KEY WORDS: Gas hydrate; dissociation; mathematical model.

INTRODUCTION

Hydrate is treated as a potential energy resource for the 21st century because a large amount of methane gas is trapped in hydrate reservoirs. In the past 30 years, considerable effort has been made for commercial production of natural gas from hydrate reservoirs. Until now, all methods are still limited to experimental scale, except for one gas-hydrate field in western Siberia, which was exploited successfully (Makogon, 1997).

To recover natural gas from hydrate dissociation, depressurization or temperature falling are effective methods which are based on breaking the temperature-pressure equilibrium conditions of gas hydrate. Extensive reviews of gas hydrate were reported by Englezos (1993).

Makogon (1997) and Sloan (1998), Burshears et al. (1986), Selim and Sloan (1989), Tsyppkin (2000), Masuda et al. (1999) presented different methods for analysis of the dissociation process of gas hydrate by

depressurization. In these models, various assumptions are adopted in order to obtain the solution, such as hydrate dissociation is considered as a moving boundary problem, the water released is not considered, the water in the reservoir remained stationary and the well temperature was kept constant or the energy contend in water is not considered. Moridis et al (1998) added a module for hydrate dissociation into the TOUGH2 general-purpose reservoir simulator. The flow of gas and water were considered and the conductive -- convective heat transfer equation was used.

Durgut and Parlaktuna (1996), Swinkels and Drenth (1999), Bondarev and Ahmadi et al. (2000) and Ji et al. (2001) used thermal stimulation for hydrate dissociation and studied the enthalpy of dissociation for hydrates of different gases. They concluded that the simulation could provide insight into the natural gas production process and for economical evaluation of different production scenarios.

In this paper, the problem of natural gas production from a depressurizing well in hydrate reservoirs is studied. The case that the well pressure is fixed, reservoir is partially saturated with hydrate, and the reservoir contains pressurized natural gas is analyzed. The energy equation including both heat conduction and convection was used in the analysis. The mass balance and heat balance at the dissociation front are included in the analysis. Governing equations are solved using a finite-difference numerical scheme.

FORMULATION OF PROBLEM

Assumptions

1. Free methane (gas), methane hydrate (solid) and water (liquid) are in thermodynamic equilibrium, the fractional volume or "porosity" of each component being ε_g , ε_h and ε_w respectively. Clearly,

$$\varepsilon_g + \varepsilon_w + \varepsilon_h + \varepsilon_m = 1 \quad (1)$$

2. Methane (gas) satisfies the ideal gas law, i.e.

$$pV = NRT \quad (2)$$

Consequently of the three quantities p, T, ρ_g , only one is independent.

Basic Relations

Relation of the fractional volumes

$$\begin{aligned}\varepsilon_h + \varepsilon_g + \varepsilon_w + \varepsilon_m &= 1 \\ \varepsilon_g - \varepsilon_{g0} &= -\beta(\varepsilon_h - \varepsilon_{h0}) \\ \varepsilon_w - \varepsilon_{w0} &= -(1-\beta)(\varepsilon_h - \varepsilon_{h0})\end{aligned}\quad (3)$$

$$\varepsilon_m = \varepsilon_{m0}$$

Conservation of mass, neglecting convective term,

$$\begin{aligned}\frac{\partial \varepsilon_g \rho_g}{\partial t} + \nabla \cdot \varepsilon_g \rho_g \bar{u}_g &= -\chi \rho_h \frac{\partial \varepsilon_h}{\partial t} \\ \frac{\partial \varepsilon_w \rho_w}{\partial t} + \nabla \cdot \varepsilon_w \rho_w \bar{u}_w &= -(1-\chi) \rho_h \frac{\partial \varepsilon_h}{\partial t}\end{aligned}\quad (4)$$

Equations of momentum equilibrium, neglecting inertia,

$$\begin{aligned}\bar{u}_g &= -\frac{K_g}{\varepsilon_g \mu_g} \nabla p \\ \bar{u}_w &= -\frac{K_w}{\varepsilon_w \mu_w} \nabla p = \frac{K_w}{\varepsilon_w \mu_w} \frac{\varepsilon_g \mu_g}{K_g} \bar{u}_g\end{aligned}\quad (5)$$

Hence

$$\frac{\partial (\varepsilon_g \rho_g + \chi \varepsilon_h \rho_h)}{\partial t} = \nabla \cdot \left(\frac{\rho_g k_g}{\mu_g} \nabla p \right)\quad (6)$$

The energy conservation equation

$$\begin{aligned}\varepsilon_g \rho_g \frac{\partial C_p T}{\partial t} + (\varepsilon_w \rho_w C_w + \varepsilon_h \rho_h C_h + \varepsilon_m \rho_m C_m) \frac{\partial T}{\partial t} \\ + \varepsilon_g \rho_g \bar{u}_g \cdot \nabla C_p T + \varepsilon_w \rho_w \bar{u}_w \cdot \nabla T\end{aligned}\quad (7)$$

$$= [\Delta H + \chi C_p T + (1-\chi) C_w T] \rho_h \frac{\partial \varepsilon_h}{\partial t} + K \nabla^2 T$$

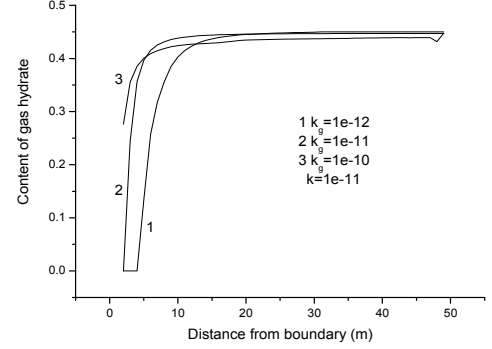
This is the equation for T (or p). In which $\varepsilon_h, \varepsilon_g, \varepsilon_w, \varepsilon_m$ are fractions of hydrate, gas, water and skeleton, respectively. β is a coefficient, p, T are pressure and temperature respectively, ρ_g, \bar{u}_g, K_g are density, velocity and permeability of gas, C_g, C_w, C_h, C_m are thermal capacities of gas, water, hydrate and skeleton respectively, ΔH is the suction heat by dissociation, χ is a coefficient, K is heat conduction coefficient.

Solutions and Analysis

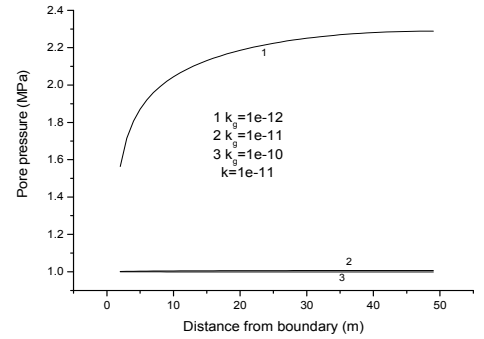
We note that in accordance with Eq. (5) ε_g and ε_h can be expressed in terms of either T or p . Hence Eq. (7) can be solved in terms of T or p under appropriate initial and boundary conditions.

Fig. 1 gives the effects of permeability of dissociated gas on

dissociation. It is shown that the dissociation rate increases with the increase of permeability of dissociated gas. This may be the fact that the gas may dissipate much fast with the increase of the permeability. The pore pressure decreases fast with the increase of the permeability of dissociated gas.



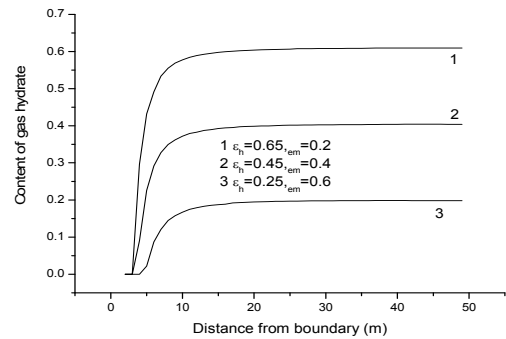
(a) changes of gas hydrate content

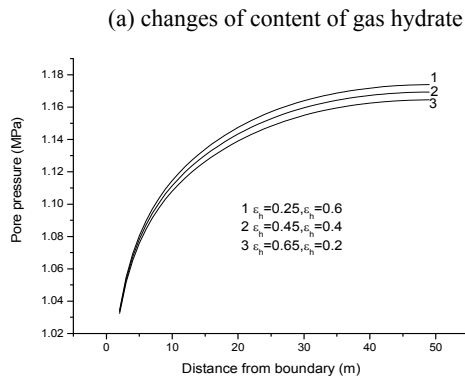


(b) changes of gas hydrate content

Fig. 1 Effects of permeability of gas on the dissociation

Fig. 2 gives the effects of initial content of gas hydrate on dissociation. It is shown that the dissociation rate increases with the increase of the initial saturation of gas hydrate. The pore pressure decreases slow with the increase of initial content of gas hydrate. The reason may be that the increase of initial saturation of gas hydrate leads to the decreases of the rock mass and water saturation, which cause the heat absorbed by gas hydrate increase and the percolation easy because of large porosity for gas to percolate.

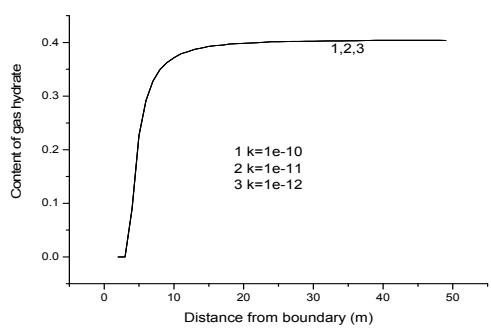




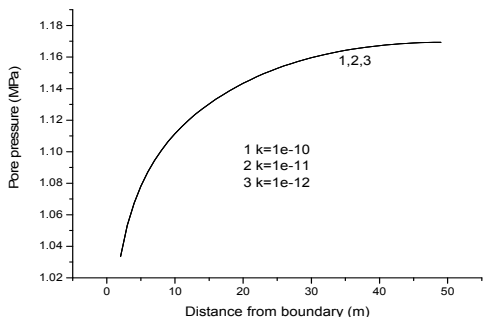
(b) changes of pore pressure

Fig. 2 Effects of initial content of gas hydrate on dissociation

Fig. 3 gives the results of effects of heat conductivity on the dissociation. It is shown that the heat conductivity has small effect on the dissociation of gas hydrate. Although the heat conductivity changes from $1 \times 10^{-9} m/s$ to $1 \times 10^{-11} m/s$, the development of pore pressure and dissociation of gas hydrate are the same.



(a) changes of gas hydrate content



(b) changes of pore pressure

Fig.3 Effects on heat conductivity on the dissociation

CONCLUTIONS

A model of the dissociation of gas hydrate is presented. The difference method is used to solve the model. The effects of factors on dissociation of the gas hydrate are investigated. Depressurization is a viable method for production of natural gas from hydrate reservoir. The dissociation temperature and pressure are slowly varying functions of time. It is shown that the controlling equations may be simplified considering that the big difference between the permeability of water and gas and the heat conduction.

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