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NUMERICAL MODELING OF GAS DISSOCIATION FROM GAS HYDRATE IN POROUS MEDIA

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Gas hydrates may become an alternative future energy resource as large in-place volumes exist within and beneath permafrost and in offshore environments. However, gas production potential from gas hydrate reservoirs using different production mechanisms has not yet been fully investigated. This paper presents an axisymmetric model for simulating gas production from hydrate decomposition in porous media by a depressurization method.

Several researchers have studied gas hydrate decomposition (Tsypkin, 1991; Ji et al., 2001; Moridis, 2002). Ullerich, Selim and Sloan (1987) described the decomposition of a synthetic core of methane hydrate as a moving boundary heat transfer problem. Most of the models assume equilibrium decomposition (Ji et al., 2001; Tsypkin, 1991). In the equilibrium models, the three-phase gas hydrate-gas-water interface is at equilibrium. Ahmadi, Ji (2003) developed an axisymmetric model for production of natural gas at a constant rate from gas hydrate-bearing reservoirs. The dissociation values of temperature, pressure and the position of the front enlisted in the table and figures displayed in the work of Ji et al. (2003) appear to be inconsistent for all different natural gas production rates. This work presents the acceptable values of dissociation temperature and pressure and location of the gas hydrate dissociation interface for different gas flow rates. A comparison of the effect of boundary conditions on temperature and pressure distribution and production rate is studied. Also, effects of variations in the reservoir porosity and zone permeability are considered.

Production of natural gas from gas hydrates by constant flowing bottom hole pressure and with fixed well output is studied. We consider the case 1 (*BC1*), where a well is drilled into a methane hydrate-bearing reservoir, and maintained at a constant pressure below the gas hydrate dissociation pressure; case 2 (*BC2*), where a well is drilled into gas hydrate-bearing reservoir sediment, and maintained at a fixed production rate. In this work we will study gas production from an unbounded axisymmetric gas hydrate-bearing reservoir that is partially saturated with gas hydrate and contains pressurized natural gas. For describing the decomposition model of case 1, the governing equations can be written in a linearized form similar to Makogon's (1997) equations for the process of gas hydrate decomposition. The linearized form of the governing equations as reported by Makogon is used in analysis of case 2. For various conditions at the well, a set of self-similar solutions for the temperature and pressure distributions in the reservoir is obtained. The outcome leads to a system of coupled algebraic equations for the location of the decomposition front and the temperature and pressure at the front. Numerical solution of the resulting system has been obtained by the Newton method of iteration. The calculations have been made for the available data of parameters listed in nomenclature.

For different well pressures (*BC1*), production rates (*BC2*) and reservoir temperatures, distribution of pressure and temperature in the porous layer of methane hydrate and in the free gas region are evaluated. The distance of the decomposition front from the well as functions of time are computed. Time variations of mass flux and total mass flow are also studied. After 60 days of gas dissociation from gas hydrate, the resulting pressure and temperature profiles in the gas hydrate reservoir under various conditions are displayed in Figure 1. Here, the permeability in the free gas zone is 5.2md and the gas hydrate zone permeability is 0.4md. Low permeabilities were used to maintain longer production periods and to avoid faster dissociation in evaluation of gas dissociation rates from gas hydrate. In this figure the pressure profiles for a well pressure of 2 MPa and a reservoir temperature of 287 K are shown by solid lines, while the pressure profiles for a fixed output of *Q*=0.04 Kg/s are shown by the dot-dash lines. Figure 1 also compares the temperature distribution obtained by BC1 shown by the dashed lines to BC2 shown by dotted lines. Here a reservoir pressure of 15 MPa, initial gas hydrate saturation of 0.19 and a reservoir porosity of 0.2 are used. The lower saturations and porosities were used to compare with other models. For reservoir temperature of 287K and pressure of 15 MPa and the natural gas production rate of 0.04 Kg/s, the dissociation temperature and pressure calculated by Ji et al. (2003) are 281.96 K and 6.65 MPa respectively. From this work, the dissociation temperature and pressure seems to be around 279.3 K and 5.14 MPa respectively. The position of the dissociation front observed from Figure 1 is around 6 m. In comparison with Ji et al. (2003), the dissociation front is at about 9 meters after 30days. Inconsistencies in these values were initially discovered for all different natural gas production rates. The dissociation values for fixed gas output were then simulated again and compared with the values of constant well pressure. Effects of boundary conditions on production profile are presented in Figure 2. The mass flow profile is almost constant

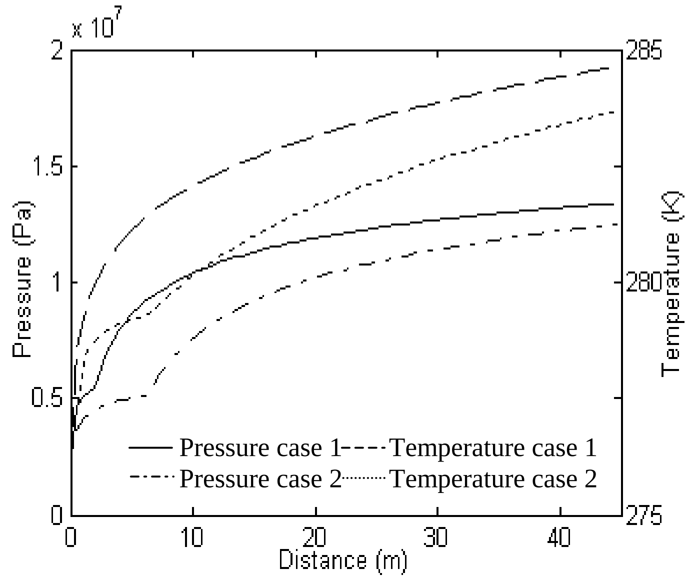

Figure 1. Temperature and pressure profile schematic in the reservoir for different well operating conditions.

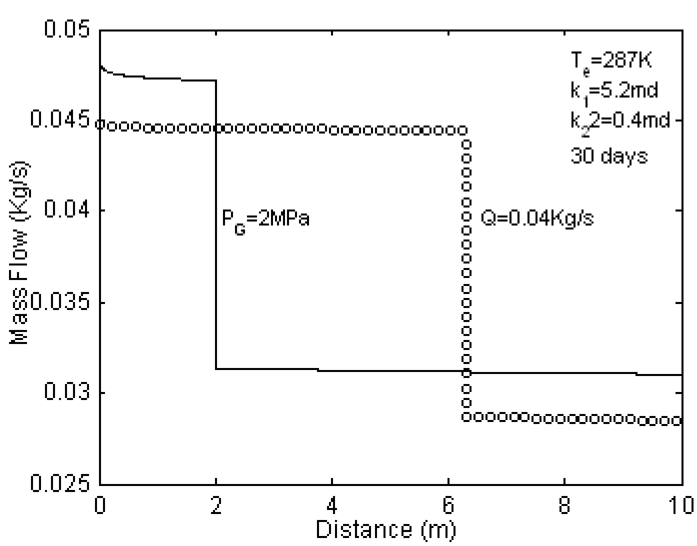

Figure 2 Comparisons of gas flow profiles for different boundary conditions.

across the reservoir when constant flow rate is employed at the well. There is a small decrease in the gas dissociation from the gas hydrate zone, which is compensated by equally small increase in gas production at the well (also observed by Ji et al.). When this case is compared to the one maintaining constant well pressure, it is observed that the *BC1* boundary condition produces more gas output than *BC2*. Also, the movement of the gas dissociation front is slower in case of *BC1* versus *BC2*, which necessitates the well in case 1 to be operated for longer periods. More gas production occurs in case 1 at the end of the process. Effects of reservoir porosity and zone permeability are also studied. The Linearization method formulated assumes that the heat convection dominates the conduction in the entire reservoir. While this assumption is reasonable away from the front, it does not allow for the energy balance at the dissociation front to be enforced. Despite this important limitation of the approach, this semi-analytical method is a convenient means for studying many features of the natural gas production from gas hydrate reservoirs.

The following conclusions are drawn from this study:

1. The natural gas output and the motion of the gas dissociation front are sensitive functions of reservoir temperature, well pressure and zone permeabilities and porosities.
2. Different pressure boundary conditions at the production well make a significant difference to the gas production rate. The well operated with constant bottom hole pressure predicts increased gas production over fixed natural gas flow rate.
3. Constant bottom hole well pressure boundary condition estimate the slower propagation of the gas dissociation front over fixed gas flow. Therefore it allows the well to operate over longer periods.

Accurate simulation study requires accurate data for methane hydrate's petrophysical and thermodynamic properties. Developing and implementing the methods to determine the petrophysical and thermodynamic properties of gas hydrate-bearing reservoirs is difficult, but critically needed. In addition to the reservoir modeling, laboratory experiments are being conducted to synthesize pure methane hydrate suitable for measurement of physical properties and decomposition behavior. One could assess gas production from the gas hydrate-bearing porous media using synthetic gas hydrate at experimental scale. Laboratory measurements could validate our simulations on comparison with the cumulative gas produced in each case. To obtain a satisfactory match of the reservoir model to the data, certain measured properties have to be tuned; these properties can be difficult to measure accurately. This comparison would increase confidence in the behavior of the model so that the model can be used to evaluate commercial gas production viability.

In summary, an analytical model is developed to predict the performance of decomposition of gas hydrate in porous media by considering the Stefan model assumption. It is an equilibrium model of gas hydrate dissociation in axisymmetric infinite homogenous gas hydrate-bearing reservoir and can evaluate pressure, temperature, gas flux and gas flow rate profiles as functions of time. The model is used to perform sensitivity studies to investigate the feasibility of commercial gas production from gas hydrate-bearing reservoirs. The results suggest that a significant quantity of gas can be produced from gas hydrate-bearing reservoirs in pressure communication with free gas-bearing reservoirs by producing and depressurizing the associated free gas.

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