MODELING THE FORMATION AND DECOMPOSITION OF GAS HYDRATES IN POROUS MEDIA

Muhamed Khairullin*, Marat Shamsiev, Petr Morozov, Adel Abdullin, Inis Salimjanov
Institute of Mechanics and Engineering
Kazan Science Center
Russian Academy of Sciences, Kazan
RUSSIA

ABSTRACT

Natural gas hydrates, consisting mainly of methane hydrate, are regarded as promising sources of energy supply. In this paper, based on numerical simulations of nonisothermal two-phase filtration in porous medium saturated with gas, water and hydrate, the analysis of depressurization in gas hydrate reservoir is performed.

Keywords: gas hydrates, depressurization, equilibrium reaction model

NOMENCLATURE

c heat capacity [J/K]
f phase permeability
g gas
H reservoir thickness [m]
h hydrate
$K_{JT}$ Joule-Thomson coefficient[K/MPa]
k absolute permeability [$\mu$m$^2$]
m porosity
p pressure [MPa]
p$_b$ bottomhole pressure [MPa]
q latent heat for hydrate dissociation [J/kg]
r$_w$ well radius [m]
S saturation
T temperature [K]
w water
z compressibility of gas
$\varepsilon$ mass fraction of gas in hydrate
$\lambda$ thermal conductivity [J/m·s·K]
$\mu$ viscosity [mPa·s]
$\eta$ adiabatic expansion coefficient [K/MPa]
$\rho$ density [kg/m$^3$]
$(\rho C)_v$ volumetric heat capacity [J/m$^3$K]

INTRODUCTION

Gas hydrates are solid crystalline compounds of gas molecules and water stable under certain pressures and temperatures. One volume of methane hydrate at pressure of 25 bar and temperature 0°C contains 180 volumes of gas. 80% of hydrate is water and 20% is gas. According to expert judgments natural gas hydrates resources are commensurate with total resources of all fossil fuels reserves recoverable by conventional methods. Therefore, the important problem is to find cost-effective technology to develop deposits of gas hydrates [1-3]. At the present time methods such as thermal stimulation, inhibitor injection, depressurization and a combination of them are considered.

Actually equilibrium and kinetic reaction models in simulating gas hydrates behavior in porous media are used. The first model is based on the condition of thermodynamic equilibrium of gas-water-hydrate in each elementary volume of porous medium [4-7]. Kinetic reaction model is based on the experimental dependence of the dissociation rate on pressure, temperature and size of hydrate particle [8]. Kowalsky and Moridis [9]

* Corresponding author: Phone: +7 (843) 231 90 57 Fax +7 (843) 236 52 89 E-mail: khairullin@mail.knc.ru
showed that the equilibrium and kinetic reaction models give similar results for wide range of large-scale hydrate production simulations.

**NUMERICAL SOLUTION**

In this paper, an axisymmetric problem of gas production from a vertical well in the reservoir saturated with thermodynamic equilibrium mixture of gas, water and hydrate is considered. It is assumed that the porous medium, gas hydrate and water are incompressible, Darcy’s law is valid for water and gas phases, the capillary effects are neglected, top and bottom of formation are heat insulated. Basic equations describing the dynamics of an equilibrium mixture of gas, water and hydrate in a porous medium are derived from the conservation laws of mass, momentum and energy [5-7]. With concerns above the energy balance equations, mass balance equations of gas and water phases are respectively given by

\[
(pC) \frac{\partial T}{\partial t} - m \rho_w \frac{\partial S_h}{\partial t} - m(1-S_w)(1-S_h) \rho_w c_w \eta \frac{\partial p}{\partial t} = \frac{1}{r} \frac{\partial}{\partial r} \left( r \lambda \frac{\partial T}{\partial r} \right) + k(S_h) \rho_w c_w \frac{f_w}{\mu_w} K_{Tr} \left( \frac{\partial p}{\partial r} \right)^2 - k(S_h) \rho_w c_w \frac{f_w}{\mu_w} + \rho_w c_w \frac{\partial p}{\partial r} \frac{\partial T}{\partial r} = 0, \quad (1)
\]

\[
m \frac{\partial}{\partial t} \left( (1-S_w)(1-S_h) \frac{p}{zRT} \right) = \frac{1}{r} \frac{\partial}{\partial r} \left( r \rho_w c_w \frac{f_w}{\mu_w} \frac{\partial p}{\partial r} \right) - m \rho_w e \frac{\partial S_h}{\partial t}, \quad (2)
\]

\[
m \frac{\partial}{\partial t} \left( (1-S_h) \frac{\partial S_h}{\partial t} \right) = \frac{1}{r} \frac{\partial}{\partial r} \left( r \rho_w c_w \frac{f_w}{\mu_w} \frac{\partial p}{\partial r} \right) - m \rho_w e \frac{\partial S_h}{\partial t}, \quad (3)
\]

The condition of thermodynamic equilibrium of gas-water-hydrate mixture is described by the empirical equation [4]:

\[
T = a \ln p + b, \quad (4)
\]

where constants \(a\) and \(b\) are determined experimentally.

The boundary conditions are

\[
p(R_w,t) = p_w, \quad T(R_w,t) = T_w, \quad p(R_e,t) = p_e
\]

and the initial conditions are

\[
S_h(r,0) = S_h^0, \quad S_w(r,0) = S_w^0, \quad T(r,0) = T_0 = a \ln p_0 + b.
\]

Mass rates of water and gas in formation conditions are defined as:

\[
Q_w = 2 \pi Hk(S_h) \rho_w \frac{f_w}{\mu_w} \frac{\partial p}{\partial r} \bigg|_{r=R_w}
\]

\[
Q_g = 2 \pi Hk(S_h) \rho_w \frac{f_w}{\mu_w} \frac{\partial p}{\partial r} \bigg|_{r=R_w}
\]

Equations from (1) to (3) are discretized in time and space with the mesh refinement in the vicinity of the well, solved by a finite differences method. The independent variables are pressure, water saturation, hydrate saturation, and temperature. Since the equations are non-linear, the solutions are obtained by using an iterative procedure.

**Results and discussions**

For the numerical simulation, the following parameters were used: \(p_w = 10\), \(p_e = 5\), \(S_w^0 = 0.39\), \(S_h^0 = 0.21\), \(r_w = 0.1\), \(R_w = 500\), \(H = 10\), \(\rho_w = 1000\), \(\rho_h = 920\), \(m = 2\), \(k = 0.01\), \(N = 2\), \(\mu_e = 1\), \(\mu_w = 0.013\), \(\varepsilon = 0.147\), \(a = 7.28\), \(b = 169.7\), \((pC)_e = 1.48\), \(\lambda = 1.71\), \(c_h = 2093\), \(c_w = 4200\), \(c_h = 3210\), \(K_T = 0.4\), \(\eta = 0.14\), \(q = 5.1 \times 10^5\). Gas phase contains only methane.

Compressibility of gas is calculated by the Latonov-Gurevich formula [7]:

\[
z(p,T) = \left[ 0.17376 \ln \left( \frac{T}{T_w} \right) + 0.73 \right] \frac{\rho}{\rho_w} + 0.1 \frac{p}{p_w}.
\]

Relative permeabilities for gas and water phase are given by [5]:

\[
f_w(S_h) = \begin{cases} (1-S_w / 0.9)^{3.5} (1+3S_w), & 0 < S_w \leq 0.9, \\ 0, & S_w \geq 0.9, \end{cases}
\]

\[
f_w(S_w) = \begin{cases} ((S_w - 0.2) / 0.8)^{3.5}, & 0.2 < S_w \leq 1, \\ 0, & 0 \leq S_w \leq 0.2 \end{cases}
\]

Figure 1 shows the curves of the spatial distribution of hydrate and water saturation at selected moments (i.e., 1, 10, 100 days). As a result of hydrate decomposition water saturation increases with time throughout the reservoir, taking its maximum value behind the front of dissociation.
Figure 1. The evolution of hydrate saturation and water saturation (1 – t=1 day, 2 – t=10 days, 3 – t=100 days).

The total amount of hydrate decomposed in a circular formation is defined as:

\[
V_h = 2\pi Rhm \int r \left( S_h^0 - S_h(r) \right) dr.
\]  

(6)

As a result of hydrate dissociation additional amount of gas from the reservoir becomes about 10⁶ m³ after 100 days.

In the process of gas production at a certain temperature and pressure conditions, gas hydrates can be formed in the vicinity of the well [7].

Figure 2 shows the distribution of hydrate and water saturation in the case of the initial reservoir pressure \( p_0 = 20 \) MPa, and bottomhole pressure \( p_c = 15 \) MPa. As the hydrate saturation in the vicinity of the well grows, gas production rate decreases.

CONCLUSIONS

The simulation runs indicated that for depressurization method the volume of hydrate decomposed insignificant compared to the total volume of hydrate in the reservoir. Therefore, for effective gas production from the hydrate deposits it is necessary to use the depressurization in combination with other methods. Nonmonotonicity of gas production rate curves and pressure curves at early time may serve as one of the diagnostic features of gas hydrates decomposition in the reservoir.

Acknowledgments

This work was carried out with financial support from the Russian Foundation for Basic Research (grant No. 11-05-00878-a).

REFERENCES

