Study on Multi-Phase Flow Rule of Horizontal Well in Deep Water Gas Hydrate Drilled by CT

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Abstract. Natural gas hydrate is an important clean energy in the future because of its high energy density, clean and pollution-free, large amount of resources and wide distribution. Coiled tubing horizontal well drilling can ensure reservoir drilling rate, increase reservoir drainage area, improve development efficiency, and solve the problem of conventional horizontal well drilling trajectory control caused by shallow hydrate reservoir. In the process of drilling horizontal wells with coiled tubing, the gas hydrate is decomposed into gaseous gas due to the change of temperature and pressure environment. The multiphase transient flow of gas in the wellbore will affect the wellbore temperature and pressure environment and cause well control risk. The calculation model of multiphase transient flow in deep water gas hydrate horizontal wells is established. The gas distribution and migration law in the wellbore are analysed. The variation of wellbore pressure and ground flow law are mastered. The theoretical basis and construction reference are provided for deep water gas hydrate continuous horizontal wells drilling.

Keywords: Deepwater, Gas hydrate, Coiled tubing drilling, Horizontal well, Multi-phase flow, Flow rule.

1. Introduction
In order to maintain the rapid development of my country's economy and meet the strict requirements of environmental protection, it is imperative to find clean energy. Among them, natural gas hydrate is an important clean energy. It has high energy density (1m³ combustible ice contains 195m³ standard natural gas), clean and pollution-free, large and widely distributed (the natural gas hydrate resources in my country’s sea waters are about 80 billion tons of oil equivalent)) [1], the efficient development of natural gas hydrates is beneficial to reducing my country’s dependence on foreign resources and maintaining the rapid, green and sustainable development of my country’s economy.

The Guangzhou Marine Geological Survey of the Ministry of Land and Resources of China successfully implemented the trial mining of natural gas hydrate in the Shenhu waters of the northern South my country Sea in May 2017, marking that my country has become the first in the world to achieve continuous trial mining of combustible ice in the sea. Countries with stable gas production [2]. However, natural gas hydrate reservoirs in the sea have the characteristics of deep-water depth (above 1000m) and shallow reservoir depth (about 200m below the seabed) [3], which is difficult to develop and costly to meet commercial mining needs. Horizontal wells can ensure reservoir drilling rate, increase reservoir
Coiled tube drilling can solve the difficult problem of conventional horizontal well drilling trajectory control caused by shallow hydrate reservoirs [4]. However, during the drilling of hydrate reservoirs, changes in the temperature and pressure environment will affect the stability of hydrates, causing natural gas hydrates to decompose into gaseous natural gas. The gas moves up the wellbore and affects bottom whole pressure stability, which may cause serious problems. Well control problem [5]. To this end, this paper establishes a deep-water natural gas hydrate horizontal well drilling wellbore multiphase flow calculation model to analyze the gas migration and distribution rules in the wellbore, as well as the wellbore pressure and surface fluid flow rules, in order to be a deep-water natural gas hydrate coiled tube horizontal well Drilling provides theoretical basis and construction reference.

2. Calculation model of multiphase flow in deep water gas hydrate horizontal well drilling wellbore

After the formation gas enters the wellbore annulus, the fluid flow in the wellbore annulus will change, from the liquid flow of drilling fluid to the complex multiphase flow of gas, liquid and solid [6]. In order to analyze the characteristics of gas invasion after hydrate decomposition during coiled tubing drilling in hydrate reservoirs, calculate the wellbore annulus flow parameters and related surface parameters after gas invasion, and establish a mathematical model of wellbore gas-liquid two-phase flow and wellbore two-phase flow mathematical model Including wellbore annulus air-liquid two-phase flow control equations and auxiliary equations.

2.1. Wellbore annulus air-liquid two-phase flow control equations

The control equations of multiphase flow in wellbore annulus include continuity equations and motion equations of each phase:

\[
\begin{align*}
\text{Gas phase continuity equation:} & \quad \frac{\partial}{\partial z} \left( A \rho_g E_g v_g \right) + \frac{\partial}{\partial t} \left( A \rho_g E_g \right) = \Gamma_g \\
\text{Liquid phase continuity equation:} & \quad \frac{\partial}{\partial z} \left( A \rho_l E_l v_l \right) + \frac{\partial}{\partial t} \left( A \rho_l E_l \right) = 0 \\
\text{Equation of motion:} & \quad \frac{\partial}{\partial t} \left( A \rho_l E_l v_l^2 + A \rho_g E_g v_g^2 \right) + \frac{\partial}{\partial z} \left( A \rho_l E_l v_l^2 + A \rho_g E_g v_g^2 \right) + A \frac{\partial P}{\partial z} + A \rho_m g + A \frac{\partial P}{\partial z} = 0
\end{align*}
\]

(1)

Where, \( A \) is the annulus cross-sectional area, m\(^2\); \( \rho_g \) is the gas density, kg/m\(^3\); \( E_g \) is the gas holdup, dimensionless; \( v_g \) is the gas flow rate, m/s; \( \Gamma_g \) is the gas source term in the continuity equation, kg/m/s; \( \rho_l \) is the drilling fluid Density, kg/m\(^3\); \( E_l \) is the fluid holdup, \( E_l + E_g = 1 \), dimensionless; \( v_l \) is the drilling fluid flow rate, m/s; \( P \) is the pressure, Pa; \( \rho_m \) is the mixture density, \( \rho_m = \rho_l E_l + \rho_g E_g \), kg/m\(^3\); \( \frac{\partial P}{\partial z} \) is the frictional pressure drop, Pa.

2.2. Solve the auxiliary equation

To solve the multiphase flow control equation set described in equation (1), the following auxiliary equations are required.

Gas density equation:

\[\rho_g = \frac{PM}{ZRT} \]  

(2)
Where, $Z$ is the gas deviation coefficient, dimensionless; $R$ is the molar gas constant, \(0.008471 \text{MPa} \cdot \text{m}^3/(\text{kmol} \cdot \text{K})\); $M_g$ is the relative molecular mass of the gas.

Gas deviation coefficient equation

The Standing-Katz deviation coefficient chart has derived a number of deviation coefficient calculation methods. This article uses the DAK model to calculate the gas deviation coefficient:

$$Z = 1 + \left[ 0.3265 - \frac{1.07}{T_p} - 0.5339 \frac{T_p}{T_p} + 0.01569 \frac{T_p}{T_p} - 0.05165 \frac{T_p}{T_p} \right] \rho_p \left[ 0.5475 - \frac{0.7361}{T_p} + \frac{0.1844}{T_p} \right] \frac{1}{\rho_p} + \left[ 0.1056 \left( \frac{0.7361}{T_p} - 0.1844 \right) \rho_p^2 + 0.6134 \left( 1 + 0.721 \rho_p^2 \right) \right] \left( \frac{\rho_p^2}{T_p} \right) \exp \left(-0.721 \rho_p^2 \right)$$

(3)

Where, $T_p$ is the pseudo-contrast temperature of the gas, which refers to the ratio of the absolute working temperature and the critical temperature of the gas, dimensionless; $\rho_p$ is the pseudo-contrast density of the gas, dimensionless.

Gas velocity and gas holdup equation:

$$v_g = C_0 v_m + v_\infty$$

(4)

$$E_g = \frac{v_{sg}}{C_0 v_m + v_\infty}$$

(5)

Where, $C_0$ is the distribution coefficient, dimensionless; $v_m$ is the gas-liquid mixing velocity, m/s; $v_\infty$ is the drift velocity, m/s; $v_{sg}$ is the gas apparent velocity, m/s; $d_e$ is the outside diameter of the drilling tool, m; $d_i$ is the borehole diameter, m; $\sigma$ is the gas-liquid surface tension, N/m.

$$\begin{cases} \text{Annular bubbly flow: } & C_0 = 1.2 + 0.371(d_e/d_i), \quad v_m = 1.53 \left( \frac{(\rho_i - \rho_g) g \sigma}{\rho_i^2} \right)^{0.25} \\ \text{Annulus slug flow: } & C_0 = 1.182 + 0.9(d_e/d_i), \quad v_\infty = \left[ 0.3 + 0.22(d_e/d_i) \right] \sqrt{\frac{(\rho_i - \rho_g) g (d_e - d_i)}{\rho_i^2}} \end{cases}$$

(6)

The annular flow pattern is divided by the Hassan-Kaber flow pattern judgment criterion [7].

2.3. Solving the annulus multiphase flow model

Initial conditions: The initial condition is the moment when the hydrate in the annulus has just decomposed, and there is no gas intrusion:

$$\begin{cases} E_g(0, j) = 0, E_i(0, j) = 1 \\ v_g(0, j) = 0, v_i(0, j) = q_i/A \\ P(0, j) = \rho g j + P_f \end{cases}$$

(7)

Where, $j$ is the position, m; $P_f$ is the annular pressure loss, MPa;

Boundary conditions: The boundary conditions include the bottom whole boundary and the well head
boundary in the hydrate decomposition process, which are used to judge the convergence of the equation:

\[
\begin{align*}
E_g(t, H) &= \frac{q_g}{C_g(q_g + q_t) + AV_o}, \quad E_i(t, H) = 1 - E_g(t, H) \\
\nu_g(t, H) &= \frac{C_g(q_g + q_t)}{A} + \nu_o, \quad \nu_i(t, H) = \frac{q_i}{AE_i(t, H)} \\
P(t, 0) &= 0.1
\end{align*}
\]

(8)

3. Calculation and analysis of multiphase flow in deep water gas hydrate horizontal well drilling wellbore

The parameters of the example well are: water depth 1300m, well depth 1745m, vertical depth 1600m, deflection point 1528m, horizontal displacement 200m, dog leg 2 5°/30m, ground temperature 20°C, ground temperature gradient 0.02°C/m, riser size 19in, conduit The depth is 1380m, the drill bit size is 4-3/4"in, the coil size is 2-7/8"in, and the drilling fluid density is 1.05g/cm3. The calculation results are shown in Figure 1 to Figure 4.

It can be seen from Figure 1 that when drilling in a hydrate reservoir, as the hydrate decomposes into a gaseous state, the bottom whole pressure gradually decreases over time. The previous change is obvious because the hydrostatic column pressure decreases greatly in the small hole within 100s. After the gas enters the large-diameter riser, the hydrostatic column pressure drop is small. In addition, due to the decrease in wellbore pressure, more hydrates will be decomposed, leading to more serious well control risks. The decrease in wellbore pressure will further increase the risk of well control. It can be seen from Figure 3 that the gas has moved to a depth of 1000m in the well at 900s and has reached the riser at this time. Due to the low temperature of the wellbore at the riser, the secondary formation temperature of hydrate may occur, blocking the wellbore or joints. Flow manifold. The gas holdup rate in the casing and riser is smaller than that in the coiled tube small hole because the diameter of the riser and the casing is larger than the coiled tube small whole diameter. Figure 2 and Figure 4 show that when drilling into a hydrate reservoir, the outlet displacement and mud pool increment increase due to the decomposition of hydrate. You can monitor the mud pool increment and outlet displacement to observe whether the drill encounters hydrate Reservoir and determine whether the hydrate is decomposed in the hydrate reservoir. Therefore, when drilling in hydrate reservoirs, in order to prevent the occurrence of well control risks, measures should be taken to prevent the decomposition of hydrates, such as controlling wellbore pressure and adding hydrate decomposition inhibitors. Real-time monitoring of mud tank increment and outlet displacement, and early warning of hydrate decomposition.

![Figure 1. Bottom hole pressure change along time](image1)

![Figure 2. Mud pool increment change along time](image2)
4. Conclusion
When drilling in a hydrate reservoir, as the hydrate decomposes into gaseous state, the bottom hole pressure gradually decreases over time. The pressure of the hydrostatic column in the early stage decreases greatly, and the pressure of the hydrostatic column decreases more as the gas enters the large diameter riser in the later stage. The lower well bottom pressure will cause more hydrates to decompose, leading to further deterioration of well control risks; gas migrates faster in the wellbore and can migrate to the riser in the short term, which may cause secondary hydrates Generated, blocking the wellbore or choke pipeline; the outlet displacement and mud pool increment increase. Real-time monitoring of the mud pool increment and outlet displacement change can be used for early warning of hydrate decomposition.

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