

Risk Analysis of Gas Hydrate Formation during Deepwater Gas Well Testing

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Abstract

During deep-water gas wells testing period, predicting the generating zone of hydrate precisely in the whole flow range (bore holes and surface flow lines) is the key prerequisite of guarantee for testing flow. The unusual deep-water environment and low gas density make it easy to meet the conditions of hydrate generation during deep-water gas wells testing period, such as low temperature and high pressure, especially under the testing conditions, for instance, near mud line, surface choke line, low gas generating rate and surface shut-in. Wherefore, in view of all the operational modes during testing period (clean-out, variable rate flow, downhole and surface shut-in), based on temperature field of the whole flow range and phase equilibrium condition of hydrate, predicting method of hydrate generation zone is published; by taking enthalpy as the object of study, temperature calculation model increases the accuracy of temperature prediction; by integration of bore holes and surface lines, predicting plate of hydrate generation in the whole flow range is published. During flow period, the generating condition of hydrate is affected by rate of flow, and the lower the rate of flow is, the wider the hydrate generation zone is; during the stage of shut-in and initial flow, if pressure of strings is higher and temperature is lower, risk of hydrate generation will be greater and hydrate generation zone will be larger, so relevant actions should be taken to restrain hydrate generation.

Keywords

Risk Analysis, Deepwater, Gas Well, DST, Gas Hydrate

1. Introduction

During deep-water testing period, prediction of hydrate generation zone is the prerequisite of prevention for hydrate and flow guarantee for the whole flow range [1]-[3], and three aspects are needed: 1) prediction of temperature and pressure—we start study

from temperature field of monophasic fluid in vertical wells, then take factors, such as two-phase flow, particular bore frame of deflected wells, marine environment and choking effect and so on, into consideration gradually. But the above study is specifically aimed at bore holes without continuously considering the surface flow lines behind bore holes; 2) determination of hydrate generation condition—in engineering applications, judgment according to empirical plate is generally of low accuracy, but statistical thermodynamic method is of general commonality and can facilitate the use of computers in a wide range of continuous calculation; 3) presentation of judgment method for hydrate generation zone—the engineering method to estimate the hydrate generation zone by means of critical temperature is simple, but of low accuracy, and the method makes temperature in bore holes not less than environment temperature a prerequisite, neglecting flow restriction and temperature drop.

Foreign scholars have given a more comprehensive exposition [4]-[6], but it lacks theoretical basis. And domestic scholars have proposed many predicting methods of hydrate generation zone in deep-water drilling bore holes and heat transfer law in bore holes during deep-water gas well test period [7]-[11], but these methods divide the whole flow range and present judgment plate of bore holes and that of surface flow lines, increasing the complexity of predicting hydrate generation. Based on the theoretical analysis, combined with specific conditions of deep-water gas wells test during different period, computing method for pressure and temperature of strings has been proposed and used to analyze the potential zone of hydrate generation under the circumstances, flow test, downhole and surface shut-in, and initial well startup by combining conditions of phase equilibrium.

2. Computing Model of Temperature Field

2.1. Temperature Field Equation of Bore Holes

Taking factors which affect temperature distribution in bore holes into comprehensive consideration, including environmental temperature, wellbore structure, structure of testing strings, job condition and formation fluid property, traditional method only based on heat transmission is changed, considering choking effect and work by volume change during flow behavior of high speed gas, and taking enthalpy of compactible gas during flow behavior as subject in the study, then temperature field equation of bore holes for deep-water wells during testing progress is established.

Hole section below mud line:

$$\begin{aligned} & \frac{2}{vr_i^2} \left(\frac{r_{io} U_{io} k_e}{k_e + T_D r_{io} U_{io}} \right) (T_{ei} - T_f) - \frac{\partial}{\partial z} \left[\rho \left(H + gz \cos \theta + \frac{1}{2} v^2 + \frac{fv^2}{2d} \right) \right] \\ & = \frac{\partial}{\partial t} \left[\rho \left(C_f T_f + gz \cos \theta + \frac{1}{2} v^2 \right) \right] \end{aligned} \quad (1)$$

In the formula: r_{ii} —inside radius of testing string, m; r_{io} —outside radius of testing string, m; U_{io} —total coefficient of heat transfer with outside surface of oil tube as datum, W/(m²·K); k_e —formation coefficient of heat transfer, W/(m·K); H —gas enthalpy,

J; T_{ei} —formation temperature, K; T_f —fluid temperature, K.

Hole section above mud line:

$$\begin{aligned} & \frac{2r_{go} U_{go}}{vr_{ii}^2} (T_{sea} - T_f) - \frac{\partial}{\partial z} \left[\rho \left(H + gz \cos \theta + \frac{1}{2} v^2 + \frac{fv^2}{2d} \right) \right] \\ & = \frac{\partial}{\partial t} \left[\rho \left(C_f T_f + gz \cos \theta + \frac{1}{2} v^2 \right) \right] \end{aligned} \quad (2)$$

In the formula: r_{go} —outside radius of marine riser, m; r_{ii} —inside radius of testing string, m; U_{go} —total coefficient of heat transfer with outside surface of marine riser as datum, W/(m²·K); T_{sea} —sea water temperature, K.

Computing formula of enthalpy is:

$$H(p, T) = \int_{T_0}^{T_i} C_p dT_f + \int_{p_0}^{p_i} V(1 - T_i \beta) d\beta \quad (3)$$

In the formula: V —specific volume, m³/kg; T_0 —temperature of triple point, K; p_0 —pressure of triple point, MPa; C_p —heat absorption capacity, J/(kg·°C); β —coefficient of thermal expansion, 1/°C.

The above formula can be transformed into differential form:

$$dH = C_p dT + \left[V - T \left(\frac{\partial V}{\partial T} \right)_p \right] dp \quad (4)$$

2.2. Computing Model for Hydrate Generation Condition

Adopting the thermodynamic computing method of hydrate generation condition, according to Vander Waals model [10], the equation of hydrate generation condition is:

$$\begin{aligned} & \frac{\Delta\mu_0}{RT_0} - \int_{T_0}^{T_H} \frac{\Delta H_0 + \Delta C_k (T_H - T_0)}{RT_H^2} dT_H + \int_{P_0}^{P_H} \frac{\Delta V}{RT_H} dP_H \\ & = \ln(f_w/f_{wr}) - \sum_{i=1}^l M_i \ln \left(1 - \sum_{j=1}^L \theta_{ij} \right) \end{aligned} \quad (5)$$

$$\ln(f_w/f_{wr}) = \ln x_w \quad (6)$$

If alcohol depressant added, formula (5) is changed into:

$$\ln(f_w/f_{wr}) = \ln y_w x_w \quad (7)$$

In these formulas: $i = 1, 2, \dots, l$; $j = 1, 2, \dots, L$; $\Delta\mu_0$ —chemical potential difference of water in blank hydrate crystal and pure water under standard state, J/mol; R —general gas coefficient, J/(mol·K); T_0 —temperature under standard state, K; T_H —phase temperature when generating hydrate, K; ΔH_0 —difference of specific enthalpy between blank hydrate crystal and pure water, J/kg; ΔC_k —difference of heat absorption capacity between blank hydrate crystal and pure water, J/(kg·K); P_0 —pressure under standard state, Pa; P_H —phase pressure when generating hydrate, Pa; ΔV —difference of specific volume between blank hydrate crystal and pure water, m³/kg; f_w —water fugacity in water rich phase, Pa; f_{wr} —water fugacity under reference state T_H and P_H ; l —amount of hydrate variety; M_i —ratio between the amount of style i vacant hole and that of hydrone in hydrate; L —amount of component generating hydrate; θ_{ij}

—probability that style i vacant hole is occupied by style j gas molecule; x_w —water molar concentration in water rich phase, dimensionless; y_w —activity coefficient in water rich phase, f . If there is inorganic salt electrolyte, computing model published by Jafa will be adopted [11].

3. Hydrate Generation Zone during Testing Period

According to the computing method of temperature in oil tubes for deep-water testing, temperature and pressure distribution of Well X1 in different testing period are predicted. Well X1 is with operating water depth of 1447.20 m, mud surface temperature of 3°C - 4°C, reservoir porosity of 25.6%, water saturation of 31.1%, and so on; component analysis indicates 0.4% of its natural gas component being CO₂, 89.961% of that is C₁, 4.843% of that being C₂, 2.23% of that being C₃ and the rest of that being other component. Gas component model is adopted to compute PVT parameters under reservoir condition: volume factor of natural gas being $3.283 \times 10^{-3} \text{ m}^3/\text{m}^3$, viscosity being 0.031 mPa·s and compressibility coefficient being 0.0137 1/MPa.

3.1. Clean-Out and Blow-Down Period

Generating zone of hydrate under different condition of gas production rate is predicted in **Figure 1**, indicating that during clean-out and blow-down period there is minimum testing flow rate because that the strings are of high pressure and low temperature during low yield period and the lower the yield is, the higher the risk of hydrate generation is.

3.2. Downhole Shut-In

With deliverability of $20 \times 10^4 \text{ m}^3/\text{d}$, generating zone of hydrate at different downhole shut-in time is showed in **Figure 2**, indicating that under the condition (deliverability

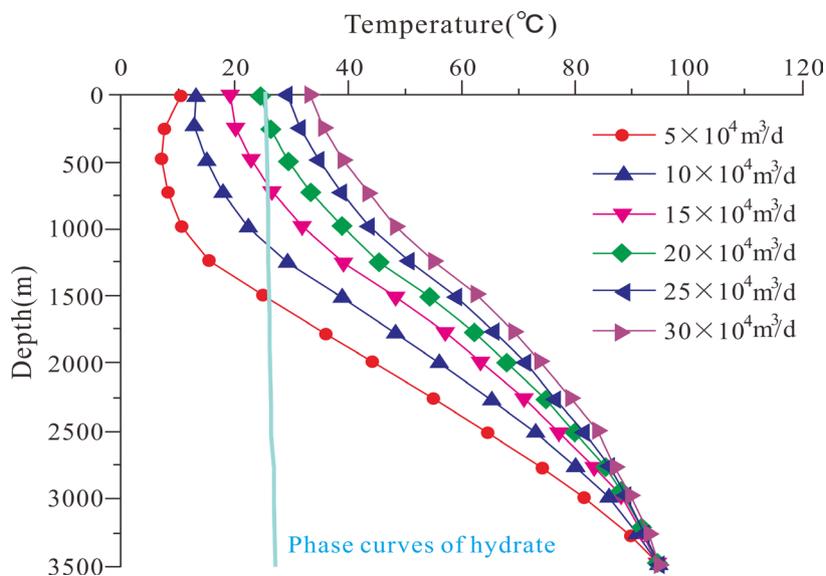


Figure 1. Generating zone of hydrate during clean-out and blow-down period.

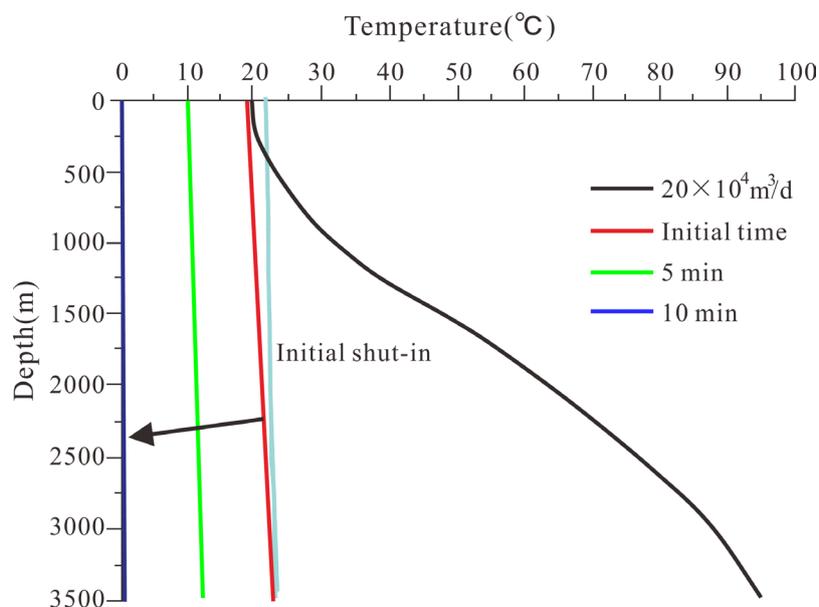


Figure 2. The generating characteristic of hydrate at different downhole shut-in time.

being $20 \times 10^4 \text{ m}^3/\text{d}$), if no preventive action is taken, there may be generating hydrate within the 600m range below the surface of the water (intersection range of temperature of strings curve and hydrate generation temperature (phase state) curve), and that after downhole shut-in, though temperature of strings decreases gradually, pressure in testing strings decreases fast and the risk of hydrate generation is low (there is no generating zone of hydrate of strings after shut-in).

3.3. Surface Shut-In

During the period of deep-water gas well test, surface shut-in can lead to serious problem of hydrate generation. Over shut-in time the temperature of strings will come into contact with environment temperature gradually, but the pressure keeps a higher value, and the zone of hydrate generation has changed gradually from the 1000 m range below the surface of the water to the 1950 m range which is 600 m below mud line. Once there is hydrate in a relatively long string, the consequences will be serious causing new difficulties for deep-water test due to hydrate being non-decomposable, so surface shut-in should be avoided (**Figure 3**).

3.4. Deliverability Testing

Figure 4 indicates that there is no risk of hydrate generation during high-speed flow period, so keeping fluid in strings flowing fast can avoid block-up caused by hydrate generation.

4. Conclusions

- 1) A new temperature and pressure calculation model during deep-water gas well

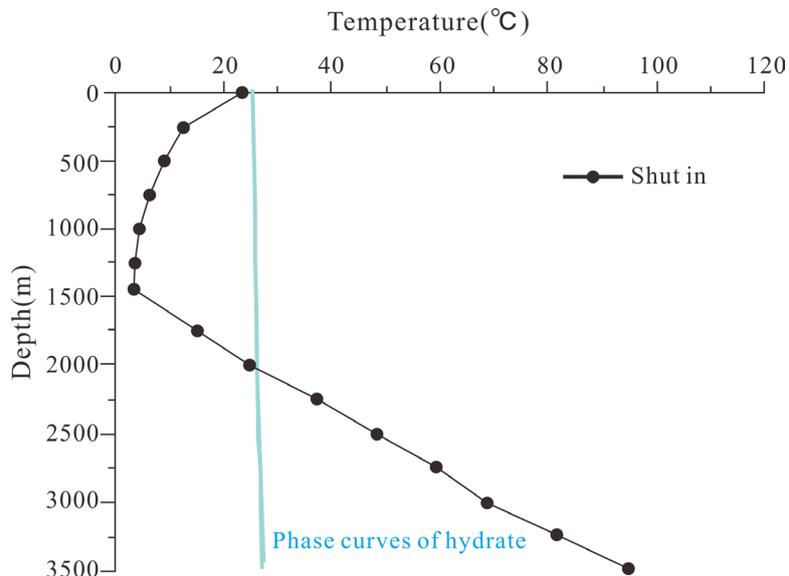


Figure 3. The generating characteristic of hydrate at different surface shut-in time.

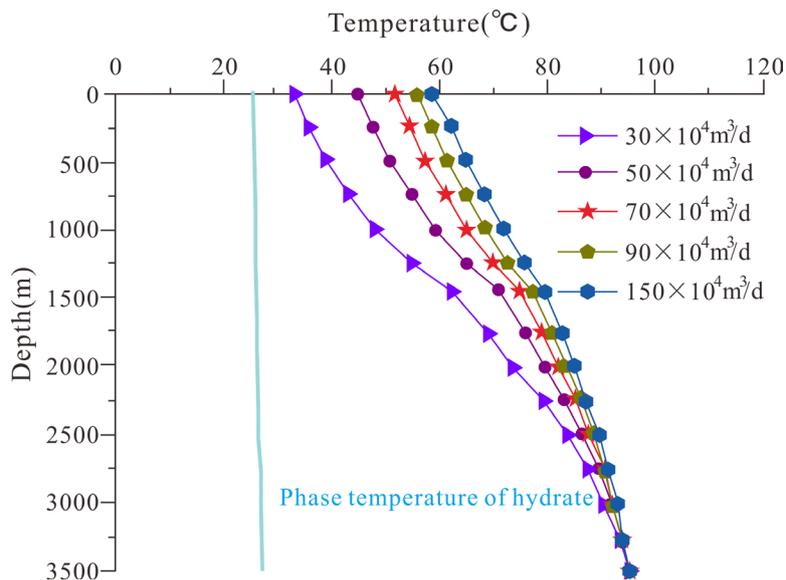


Figure 4. The generating characteristic of hydrate under high-speed flow condition.

testing has built up, and prediction method of hydrate form region at different construction stages in testing is obtained combining with the formation condition of hydrate.

2) Result shows that the surface shut-in period has the risk of hydrate generation, in which gas hydrate is easy to generate as the temperature of and inside strings gradually decreases to the seawater temperature.

3) During flow period, the lower the yield is, the higher the risk of hydrate generation is. At the stage of initial well startup, the high pressure and low temperature make it

easy for gas hydrate to generate.

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