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Study on the Optimization Design of Gas Lift Technology in Hydrate Reservoir

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Abstract: The exploitation potential of natural gas hydrate is huge. Many countries in the world have carried out research and exploration on the key technologies of natural gas hydrate exploitation. At present, depressurization production of natural gas hydrate is mainly adopted. Due to the limited area of offshore platforms and the limited artificial lift options, gas lift technology, as a mature artificial lift method, has been widely applied in onshore and offshore oil and gas fields, but has not been applied in hydrate reservoir. In this paper, the gas lift technology is proposed as the main means of hydrate depressurization production, and the optimization design of gas lift technology parameters of hydrate reservoir is carried out on the basis of the optimization of multiphase pipe flow calculation model. The calculation results show that the gas lift technology can significantly reduce the bottom hole pressure of the wellbore and can be effectively used for depressurization and drainage of the hydrate reservoir. With the increase of the depth of the gas lift string, the gas injection required to achieve the same bottom hole flow pressure will decrease continuously. In the initial stage of the test production of the hydrate reservoir, attention should be paid to optimizing the depressurization rate to avoid the phenomenon of freezing block near the well of the hydrate reservoir and the secondary generation of the hydrate in the wellbore.

Keywords: Hydrate, Gas Lift, Optimization, Depressurization

1. Introduction

Natural gas hydrates are a class of natural gas cages composed of small gas molecules and water in a solid, non-stoichiometric compound that forms at low temperatures and high pressures. The guest molecules are usually low molecular weight gases, and the main water molecules form complex arrays or cages around the guest molecules. As a highly representative unconventional new energy source in the new century, natural gas hydrates are widely distributed, have huge reserves, are green and efficient compared with other energy sources, and have great resource prospects. With the increasing understanding of the distribution as well as concentration of gas hydrate in marine sediments, the estimation of gas hydrate reserves has become more accurate. Currently, the estimated reserves of gas hydrate reservoirs are 1×10^{14} to $1\times10^{15}m^3$. Such huge reserves and the stimulation and guidance of national strategies provide a constant impetus for the research and exploitation of gas hydrates [1-5].

There are five main methods of natural gas hydrate extraction: depressurization extraction, thermal stimulation extraction, chemical inhibitor extraction, solid fluidization extraction and CO_2 alternative methods. In this paper, we will carry out a special study on the application of gas lift method in the buck extraction of hydrate reservoirs based on the preferred gas-liquid multiphase pipe flow model.

2. Wellbore Gas-Liquid Two-Phase Flow Model

There are four main models commonly used in current engineering to calculate pressure drop in gas-liquid two-phase flow: Beggs-Brill model, Orkiszewski model, Gray model, and Hagedorn-Brown model for preferential calculation.

2.1. Beggs-Brill Model

The Beggs-Brill model can be used to calculate the pressure loss of gas-liquid two-phase flow processes in horizontal, vertical and arbitrary well inclination angles, and the Beggs-Brill model classifies the flow types of two-phase flow into: separated flow, transition flow, intermittent flow and dispersion flow, and calculates the liquid content rate of the horizontal pipe cross-section according to the different flow types, and then converts the liquid content rate of the horizontal pipe cross-section into the liquid content rate of the cross-section with inclination angle by the inclination angle correction coefficient [6-10]. The pressure loss of the corresponding flow type is calculated separately. The model is based on the equation of energy conservation and pressure gradient for homogeneous flow, and experiments are conducted using air and water to measure the liquid holding rate and pressure gradient for different gas flow rates and different flow types.

The Beggs-Brill model considers that the pressure loss per unit mass of a gas-liquid two-phase mixture arises from the pressure loss due to potential, friction and acceleration. The total pressure loss equation is given by

$$-\frac{dp}{dZ} = \rho g \sin\theta + \rho\frac{dE}{dZ} + \rho v\frac{dv}{dZ}$$

Of which, the potential pressure loss.

$$\left(\frac{dp}{dZ}\right)_1 = \rho g \sin\theta = \left[\rho_L H_L + \rho_g(1-H_L)\right] g \sin\theta$$

Frictional pressure loss.

$$\left(\frac{dp}{dZ}\right)_2 = \lambda\frac{v^2}{2D}\rho = \lambda\frac{G/A}{2D}v$$

Acceleration pressure loss.

$$\left(\frac{dp}{dZ}\right)_3 = \rho v\frac{dv}{dZ}$$

2.2. Orkiszewski Model

Orkiszewski divided the two-phase flow into four flow types: bubble flow, segment plug flow, transition flow and ring mist flow [11-15]. The boundaries of each flow type are shown in Table 1 below.

Table 1. *Orkiszewski model flow type division boundaries.*

Flow Type	Boundaries
Bubble Flow	$\frac{q_g}{q_l} < L_B$
Segment plug flow	$\frac{q_g}{q_l} > L_B, \overline{v_g} < L_s$
Transition Flow	$L_M > \overline{v_g} > L_s$
Fog Stream	$\overline{v_g} > L_M$

Average density of gas-liquid two-phase at different flow patterns $\overline{\rho_m}$ and friction loss gradient τ_f are calculated in different ways.

1) Bubble flow
Average density.

$$\overline{\rho_m} = H_L\rho_L + H_g\rho_g = (1-H_g)\rho_L + H_g\rho_g$$

Frictional loss gradient.

$$\tau_f = f\frac{\rho_L}{D}\frac{v_{LH}^2}{2}$$

2) Section plug flow
Average density.

$$\overline{\rho_m} = \frac{W_t+\rho_l v_s A_p}{q_t+v_s A_p} + \delta\rho_l$$

Frictional loss gradient.

$$\tau_f = \frac{f\rho_l v_t^2}{2D}\left(\frac{q_L+v_s A_p}{q_t+v_s A_p} + \delta\right)$$

3) Transition flow
Since the transition flow cannot be calculated directly, it is first calculated by segment plug flow and fog flow, and then the corresponding values are determined according to the interpolation method.
Average density.

$$\overline{\rho_m} = \frac{L_M-\overline{v_g}}{L_M-L_s}\rho_{sL} + \frac{\overline{v_g}-L_s}{L_M-L_s}\rho_{Mi}$$

Frictional loss gradient.

$$\tau_f = \frac{L_M-\overline{v_g}}{L_M-L_s}\tau_{sL} + \frac{\overline{v_g}-L_s}{L_M-L_s}\tau_{Mi}$$

4) Mist flow
Average density.

$$\overline{\rho_m} = H_L\rho_L + H_g\rho_g = (1-H_g)\rho_L + H_g\rho_g$$

Frictional loss gradient.

$$\tau_f = f\frac{\rho_g v_{sg}^2}{2D}$$

2.3. Gray Model

Gray takes into account the presence of additional phases during gas-liquid two-phase flow, and the pressure gradient equation is improved as

$$dp = \frac{g}{g_c}\left[\xi_{\rho g} + (1-\xi)_{\rho 1}\right]dh + \frac{f_t G^2}{2g_c D\rho_{mf}}dh - \frac{G^2}{g_c}d\left(\frac{1}{\rho_{mi}}\right)$$

In practical situations, only basic data on the phase behavior of the system are usually available. With this in mind, Gray has developed a simplified empirical model of two-phase flow using data from a number of systems, requiring only gas-to-liquid ratio, pressure and temperature related data to solve the flow model, with the gas compression coefficient calculated from the gas composition components [16-19].

Through the gauge analysis of two-phase flow and indoor experiments, there are three main factors that affect the gas content rate.

$$N_r = \frac{\rho_m^2 V_{sm}^4}{g\tau(\rho_l - \rho_g)}$$

$$N_p = \frac{g(\rho_1 - \rho_g)D^2}{\tau}$$

$$R = \frac{V_{so} + V_{sw}}{V_{Bg}}$$

The correlation equation for the volume fraction of the gas obtained from the analysis of the field data is

$$\xi = \left\{ \frac{1 - Exp\left\{-2.314\left[N_v\left(1 + \frac{205.0}{N_D}\right)\right]^n\right\}}{R+1} \right\}$$

Among them

$$B = 0.0814\left[1 - 0.554\, ln\left(1 + \frac{730R}{R+1}\right)\right]$$

2.4. Hagedorn-Brown Model

The Hagedorn-Brown model takes full account of the effects of gas-liquid ratio, fluid viscosity and surface tension by using experimental data in long thin tubing to Hagedorn and Brown derived the flow energy equation starting from the steady flow energy relationship for single-phase flow as follows

$$10^6 \frac{\Delta p}{\Delta H} = \rho_m g + \frac{f_m q_L^2 M_t^2}{9.21 \times 10^9 \rho_m d^5} + \frac{\rho_m\left(\frac{u_m^2}{2}\right)}{\Delta H}$$

Hagedorn and Brown's study neither divided the flow pattern nor established an independent relationship, by defining the Reynolds number of the two phases, the friction factor of the two-phase flow can be determined from the conventional two-phase flow friction factor diagram. Hagedorn and Brown found that in many cases, the pressure loss due to kinetic energy loss is a considerable proportion of the total pressure loss when low tubing pressure is encountered. Under such conditions, the kinetic energy loss term cannot be neglected [20-24].

3. Model Selection

Since the models are not universally applicable, the target wellbore wall roughness, tubing diameter, production gas-liquid ratio, etc. may affect the accuracy of the model calculation, so it is necessary to verify and screen the appropriate two-phase tubing flow models with the specific production conditions and production data of the target production location, and to select the model with the least error for the optimal design of gas lift wells in hydrate reservoirs.

The flow pattern of the Beggs-Brill model is determined by Beggs-Brill and combined with the Taitel-Dukler model, which is based on experimental gas-water two-phase flow in horizontal and inclined pipes, and is plotted. The model first calculates the holding rate for horizontal flow, and in the inclined condition, the inclination angle is then corrected for the horizontal holding rate. the Beggs-Brill model is applicable to inclined flow at all angles from -90°-+90° and has a high accuracy in pressure drop prediction and holding rate calculation [25].

The Orkiszewski model is used for pressure drop loss, liquid holding rate and flow pattern determination in gas-water two-phase flow. Four flow types are considered: bubbly flow, segment plug flow, transition flow and mist flow. The model liquid holding rate calculation method is derived from the observed experimental phenomena and adjusted for the deviation angle, but there is a large gap with the actual production process.

The Hagedorn-Brown model was derived after an experimental study of the pressure gradient of a continuous two-phase flow in a small-diameter vertical pipe. Various different liquid flow rates, gas-liquid ratios and liquid viscosities were tested and all the related equations involve only dimensionless quantities. Therefore, it is mainly applicable to the prediction of two-phase flow in small-sized oil pipes.

The Gray model was obtained for natural gas and condensate flow in vertical pipe flow with a predominantly gas phase. The model treats the flow as a single phase, but the accuracy of the pressure drop calculation decreases rapidly with increasing water volume.

The general gas production during the production of hydrate reservoir can reach $0.3\times10^4 m^3/d$-$2\times10^4 m^3/d$, while the water production can reach more than $100 m^3/d$, so the Gray model cannot be applied. The size of the oil pipe applicable to the production of hydrate reservoir is generally larger, even if continuous oil pipe is used for gas lift, and the size is more than 1.5 inch so the Hagedorn-Brown model cannot be applied. In view of the fact that the Orkiszewski model will show unstable data when the gas volume is large in the actual calculation process, the Beggs-Brill model is used in this paper for the optimal design of gas-water two-phase flow in the oil pipeline.

4. Optimal Design of Gas Lift Parameters for Hydrate Reservoirs

In 2008, a short-term production trial of natural gas hydrates was conducted in the Mallik area of the Canadian Delta using thermal excitation, depressurization, and a combination of both, and a successful trial was conducted in 2012 in the northern Alaskan slope using a depressurization method as the primary method, supplemented by CO_2 replacement, but simulations revealed that the depressurization method contributed the majority of the gas production. In 2013, the world's first field test of marine gas hydrate production was conducted in the Daini Atsumi Knoll area at the eastern end of the Nankai Strait off the Pacific coast of Japan, successfully recovering $12\times10^4 m^3$ with an average gas production of $2\times10^4 m^3/d$. The operation was terminated prematurely due to sand emergence problems, and the long-term dynamics of gas production could not be observed. In 2017, a second round of In 2017, the second round of trial production was conducted in the same sea area, with improved sand control measures, Geoform sand control system was adopted for effective sand control, and two straight wells were used for alternate production, and the total gas production reached more than $20\times10^4 m^3$, with an average gas production of $1\times10^4 m^3$. In 2017, the China Geological Survey implemented the first deep cemented silt reservoir hydrate extraction in the Shenhu sea area of the South China Sea, using the "formation saturation". The first hydrate extraction from deep cemented silt reservoirs was carried out in the Shenhu Sea in 2017, using the "formation saturation fluid extraction method" to collect free gas and water-soluble gas in a direct well.

In this paper, we propose to use gas lift for production of hydrate reservoir, and the well type is selected as horizontal well, and the schematic diagram of production tubing column is shown in Figure 1.

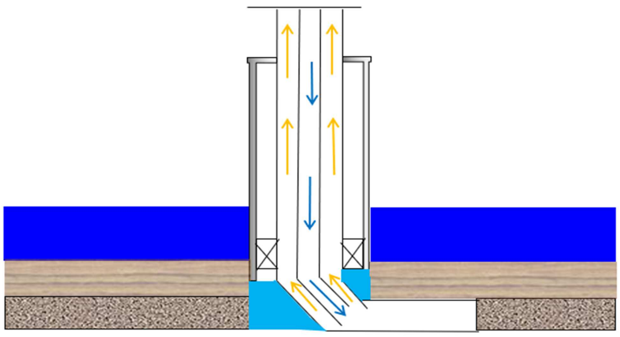

Figure 1. Schematic diagram of gas lift production pipeline column for hydrate reservoir.

From the figure, it can be seen that the double-tube gas lift actually divides the flow into three parts, namely, the hydrate reservoir inflow part, the coiled tubing injection part and the annulus recovery part. Using the nodal analysis method, the bottomhole pressure is used as the calculation node, and the bottomhole flow pressure generated due to gas injection needs to just meet the requirements of formation gas production, formation water production and wellbore lift, i.e., the three various systems reach equilibrium at the node.

A horizontal well of hydrate reservoir in South China Sea is carrying out trial production work, and it is planned to drain the hydrate reservoir by positive lift. The well has a vertical depth of 2000m, and 5 inch pipe is used to drill through the hydrate reservoir, and then 2 inch coiled tubing is lowered for gas lift. The predicted gas production of hydrate reservoir is $15000m^3/d$, water production is $100m^3/d$, and the flow pressure at the bottom of the well is 7MPa. The Beggs-Brill model is selected for the calculation model of gas-liquid two-phase flow in the process of hydrate reservoir drainage.

4.1. Influence of Different Injection Depths on the Amount of Gas Injected

For different 2inch coiled tubing down depths, different gas injection volumes are used for liquid discharge and gas recovery, setting the wellhead oil pressure to 0.4MPa, and using the nodal system analysis method, the calculated gas injection volumes under different tubing down depths are shown in Figure 2.

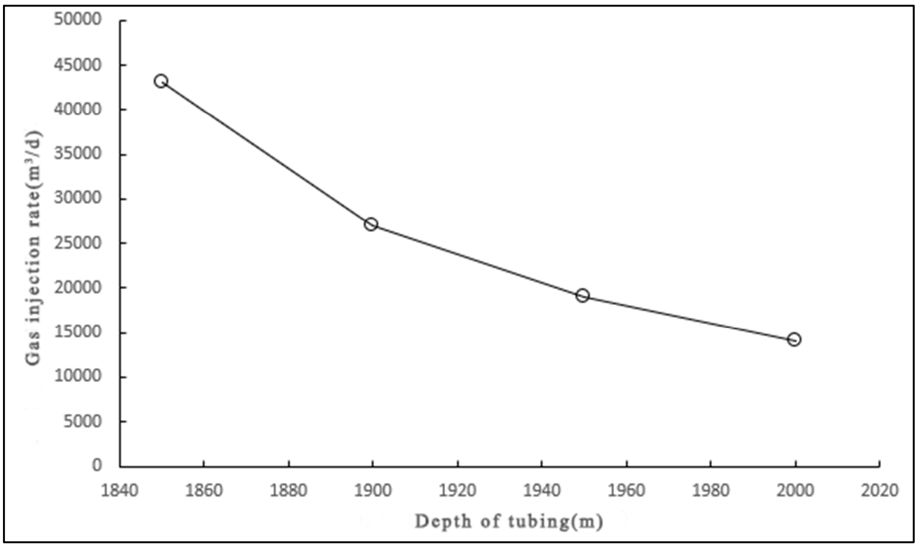

Figure 2. Gas injection volume for different depths under the oil pipe.

From the above graph, it can be seen that the amount of gas injection required to achieve gas lift extraction is decreasing as the depth of the continuous oil pipeline down increases, indicating that the greater the depth of the continuous oil pipeline down can improve the gas injection efficiency during gas lift.

4.2. Effect of Different Injection Depths on the Injection Pressure

Using the nodal system analysis method, the calculation results of the gas injection pressure under different oil pipe down depth are shown in Figure 3.

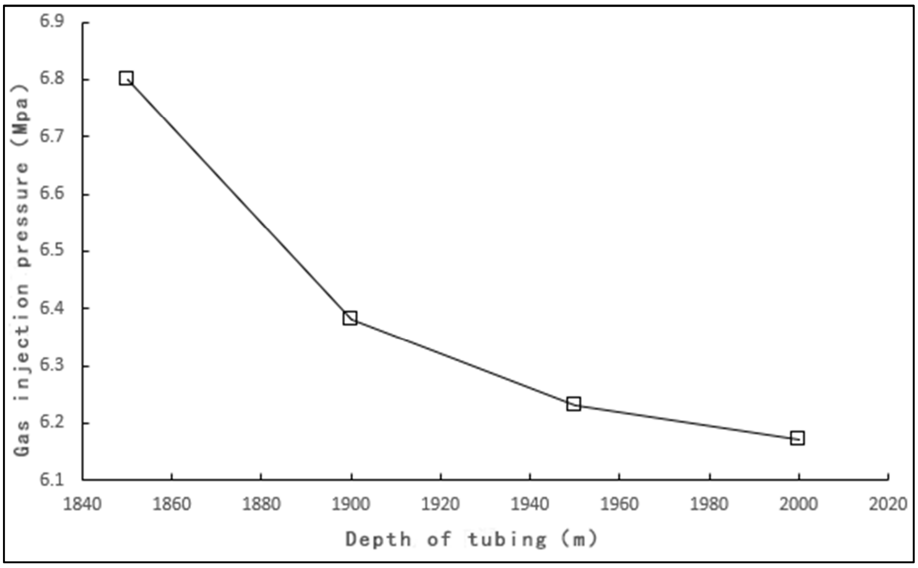

Figure 3. *Injection pressure for different depths under the oil pipe.*

From the above figure, it can be seen that, similar to the pattern of gas injection pressure, the gas injection pressure also tends to decrease with the increase of coiled tubing depth. Therefore, it is suggested that when using double-tube gas lift in hydrate reservoir trial production, it is recommended to design a deeper entry depth of coiled tubing as much as possible, so that the efficiency of gas injection can be improved on the one hand, and a lower flow pressure can be obtained on the other.

4.3. Some Issues to Note in Gas Lifting for Hydrate Reservoirs

In the start-up phase of hydrate reservoir trial production, it is necessary to consider the mutual matching between the evacuation rate of liquid in the wellbore and the decomposition rate of hydrate reservoir. As shown in Figure 4, if the injection volume is too large at the early stage of gas lift extraction, the liquid in the wellbore will be emptied rapidly and the pressure at the bottom of the well will drop rapidly, which will make the hydrate decompose rapidly and increase the gas production instantaneously on the one hand, and the cooling brought by the decomposition will easily lead to the hydrate reservoir freezing and blocking again on the other hand.

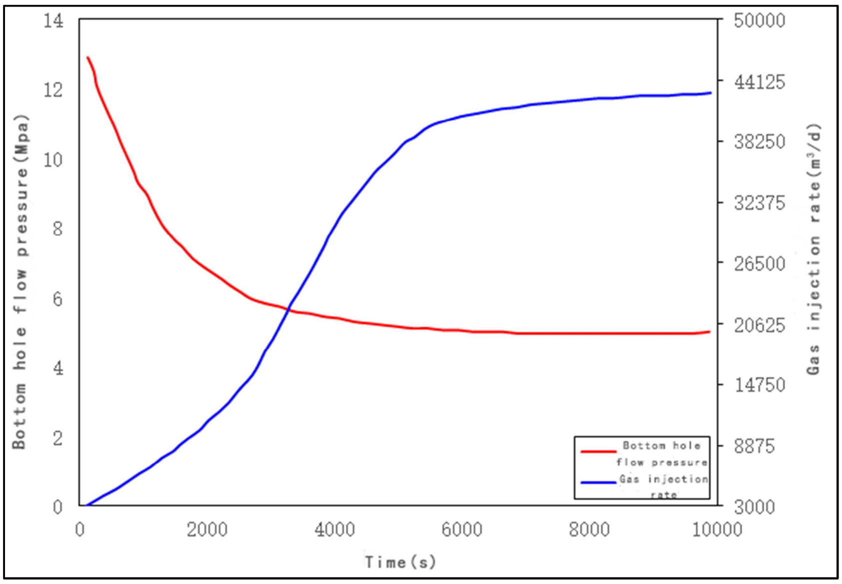

Figure 4. *Variation of gas injection volume at the early stage of hydrate reservoir trial production.*

5. Conclusion

(1) The calculation principles and adaptability of Beggs-Brill model, Orkiszewski model, Gray model and Hagedorn-Brown model methods are compared and analyzed, and the Beggs-Brill model is preferred as the base model for the optimal design of gas lift

technology in hydrate reservoir.

(2) With the increase of depth of gas lift string, the gas injection volume and gas injection pressure will decrease and the gas injection efficiency will increase. it is recommended to use a larger string depth for the design of gas lift parameters.

(3) The rapid drop in pressure drop during the start-up of a double-tube gas lift may lead to freeze block of hydrate reservoir and secondary generation of hydrate in the wellbore, and the gas injection process needs to be optimized.

(4) The gas lift technology can be applied to the relief and drainage of hydrate Wells and avoid the secondary generation of hydrate in the wellbore, which plays a positive role in the effective exploitation of hydrate Wells and has great promotion value in the production site.

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