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# The forecasting of natural gas hydrate by using P-T figure method in gas well

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*Abstract*— **Natural gas hydrate is crystalline clathrate compound. It's formed by water and natural gas at low temperatures and high pressure. In the process of gas well's production, it has the potential to form hydrate crystal layer and adhere to the pipe wall, even block the entire pipeline. Considering the coupling of temperature and pressure, this paper calculates the distribution of temperature and pressure in tube from the bottom by way of the point-to-point iteration, and then identifies whether the hydrate was generated with the point-to-point discrimination by using the P-T figure method. Through example, we know that the wellbore pressure and temperature coupling algorithm and P-T figure method are easy to use, and the result is precision enough. It can be used to analysis and calculation the production wells and test wells's distribution of pressure and temperature and hydrate formation prediction, it can be satisfied the engineering requirement.**

*Index Terms*—**gas well; hydrate; temperature; pressure prediction; P-T figure method**

## I Introduction

The formed and distribution of natural gas hydrate is influenced by temperatures、pressure and the source of the hydrocarbon gas mainly. In addition, the form of the natural gas hydrate also need enough natural gas and water-bearing medium. The basic conditions[1] of forming natural gas hydrate mainly includes: ① the temperature of gas should be equal to or lower than the water vapour's dew point that in natural gas and there should be free water in the components; ②low temperature, it should be reach the hydrate formation temperature point; ③high pressure; ④other conditions, such as high velocity、pressure surge、acid gas 、tiny hydration crystal nucleus and so on.

## Ⅱ wellbore pressure and temperature distribution

The are many factors to influence the wellbore pressure and temperature distribution, such as gas production rate、the tubing diameter and surface properties、well depth and well bore structure、 reservoir pressure and temperature、the content composition well flow、geothermal gradient etc. The laws of its influence are followed behind. [2]

1).The higher of the reservoir's pressure, the higher of the wellbore's pressure and there well be more danger;

2).The higher of the reservoir's temperature, the higher of the wellbore's temperature. The possibility to form hydrate well be more less.

3) There will be a big reduce of the wellhead pressure as well as the increase of gas production. In addition, the time for heat dissipation is very short and the temperature of the wellhead is high and the chance to form hydrate will reduce.

4).The heat dissipation area will increase as will as the tubing size increase, the temperature decreased by a wide margin. Because of joule Thomson effect, the temperature will decreased by a wider margin when the tubing size was too small. Therefore, for a certain gas production, there is an optimal pipe diameter to make the risk of hydrate formation minimize.

5).The deeper of the well and the bigger temperature reduction, the higher risk to form hydrate near the wellhead.

There will be a small amount of liquid in the well flow generally, the flow in the tubing include gas and liquid. Due to its gas liquid ratio is much higher than the oil well, the liquid will appeared as scattered small droplet and distribution in the gas evenly and the well flow will looked like fog. According to the wellbore pressure and temperature coupling algorithm which is put forward by literature 3, a model that calculated wellbore pressure and temperature piecewise was established.

According to the model, we divided the wellbore into n sections equidistantly upward from the bottom of the well and got the following formulas to calculate the fluid pressure and fluid temperature of any section's export which we called J point. Formula[3] follows:

$$p_j = p_{j-1} - \frac{\rho_L q_L + b_2 m_G q_{Gsc}}{qL + b_1 q_{Gsc}\frac{I_{j-1}+I_j}{2}} \left[ \begin{array}{l} \frac{b_3 q_{Gsc}^2}{2d_i^4}\left(I_j^2 - I_{j-1}^2\right) + g\cos\alpha\left(l_j - l_{j-1}\right) + \\ \frac{b_3\lambda q_{Gsc}^2}{4d_i^5}\left(I_{j-1}^2 + I_j^2\right)\left(l_j - l_{j-1}\right) \end{array} \right] \times 10^{-6} \qquad (1)$$

$$T_{fj} = T_{ej} + e^{-A\left(L_j - L_{j-1}\right)}\left(T_{f(j-1)} - T_{e(j-1)}\right) + \frac{1 - e^{-A\left(L_j - L_{j-1}\right)}}{A} \times \left[ \begin{array}{l} \mu_{Jm}\frac{p_j - p_{j-1}}{l_j - l_{j-1}} - \frac{V_j^2 - V_{j-1}^2}{2C_{pm}\left(l_j - l_{j-1}\right)} - \\ \frac{g\cos\alpha_j}{C_{pm}} + g_e\cos\alpha_j \end{array} \right] \qquad (2)$$

In the above formula: $b_1=4\times10^{-9}$, $b_2=4.814\times10^{-7}$, $b_3=2.6\times10^{-17}$; $I=ZT/P$;Z is compressibility factor; T is temperature,(K); P is pressure,(MPa); $\alpha$ is hole deviation angle,(°); $\lambda$ is friction coefficient of pipeline; $l$ is the length of borehole,(m); $m_G$ is the molecular weight of natural gas; g is gravitational acceleration; $d_i$ is the inside diameter of pipeline,(m) ; $T_f$、$T_e$ is the temperature of the airflow and formation,(k); V is air velocity,(m/s); A is relaxation distance; $g_e$ is geothermal gradient, ℃/m; $C_{pm}$ is the specific heat at constant pressure of gas-liquid mixture, J/(kg·k); $\mu_{Jm}$ is Joule-Thomson coefficient, K/MPa.

With formulas (1) and (2), use the coupling iterative algorithm and piecewise calculation from the bottom upward or downward from the mouth of the well, then we can get the pressure and temperature distribution of the wellbore.

## III Hydrate formation prediction

There are three methods that we often used to prediction hydrate, P-T figure method, Bono maleev method and thermodynamics method. Among them, the P-T figure method is the method that predict with the hydrate formation characteristics. For some natural that it's relative density is certain and it's under a certainly temperature or pressure, then the pressure or temperature to form natural gas hydrate is also certain. With the temperature and pressure distribution in the wellbore, we can get the results through compared the hydrate formation pressure and temperature chart or directly through iterative calculation. This method is simple in calculation、easy to use and with a high precision. Bono maleev sort out experimental data and get the natural gas hydrate formation conditions under different gas density, it's a empirical formula and used to predict the formation of natural gas hydrate. We called this method Bono maleev method, it's simple and easy to use but the calculation accuracy is not high and can only be used for preliminary estimates. Thermodynamic model was developed according to the theory of natural gas hydrate phase equilibrium model, the vast majority of the theoretical model of hydrate phase equilibrium conditions are based on Van der Waals-Platteeuw statistical thermodynamic model. Thermodynamics method calculation accuracy is higher than other methods, but the model is too complicated, it's not so convenient for actual project.

Researchers compared these methods and they got some useful conclusion[4], thermodynamics method has the highest precision, the predicted results of Bono maleev method has the highest security for industrial production, P-T figure method can meet the demand of industry in precision and security. In order to balance precision and security, we use P-T method in this article for hydrate formation prediction.

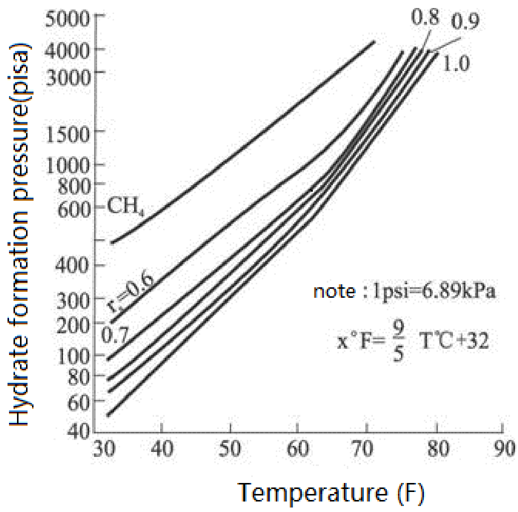


Fig 1 Hydrate formation pressure-temperature chart

For some natural that it's relative density is certain and it's under a certainly temperature or pressure, then the pressure or temperature to form natural gas hydrate is also certain[5]. P-T figure method is usually adopted to Dubois chart[6]（fig 1）. Use the pressure-temperature chart for hydrate formation prediction, we can get the lowest temperature that won't formation hydrate if we know the density of gas or we can get the lowest pressure that will formation hydrate if we know the temperature. With the development of computer technology, we can get the results directly by iterative computation computer program and no need to check the chart(The iterative formula[7] as shown in table 1 and table 2)

Table 1 iterative formula for the lowest pressure that will formation hydrate when the temperature has been known

| Relative density | The temperature range（℃） | Hydrate formation pressure（MPa） |
|---|---|---|
| 1.0 | 1.27≤T≤16.33 | P=e^(0.14202T+2.5248)×0.02618 |
| | 16.33≤T≤26.27 | P=e^(0.21204T+3.7696)×0.002355 |
| 0.9 | 1.05≤T≤16.72 | P=e^(0.13644T+2.4256)×0.03567 |
| | 16.72≤T≤25.88 | P=e^(0.20808T+3.6992)×0.00302 |
| 0.8 | 0.5≤T≤17.94 | P=e^(0.13176T+2.3420)×0.04813 |
| | 17.94≤T≤25.5 | P=e^(0.20916T+3.7184)×0.003177 |
| 0.7 | 0.5≤T≤18.38 | P=e^(0.12816T+2.2784)×0.06543 |
| | 18.38≤T≤25 | P=e^(0.20862T+2.7088)×0.00368 |
| 0.6 | 0.38≤T≤19.5 | P=e^(0.12078T+2.1472)×0.11428 |
| | 19.5≤T≤23.61 | P=e^(0.23958T+4.2592)×0.00137 |
| 0.55 | 0.5≤T≤14.77 | P=e^(0.10512T+1.8688)×0.3997 |
| | 14.77≤T≤20.72 | P=e^(0.13878T+2.4672)×0.13159 |
| G is between $r_{g1}$ and $r_{g2}$（Using the interpolation method） | $P=P_1-(P_2-P_1)\times(r_{g1}-r_g)/(r_{g1}-r_{g2})$<br>(1) $r_g$—The relative density of gas， $r_{g1}< r_g< r_{g2}$<br>(2) $P_1$、$P_2$—The pressure to formation hydrate when the temperature has be known and the relative density of gas were $r_{g1}$ and $r_{g2}$ | |

Table 2 iterative formula for the lowest temperature that won't formation hydrate when the pressure has been known

| Relative density | The pressure range（MPa） | Hydrate formation temperature（℃） |
|---|---|---|
| 1.0 | 0.4137≤P≤3.4475 | T=log(p/3.7973)×7.04-17.78 |
| | 3.4475≤P≤27.58 | T=log(p/0.3416)×4.716-17.78 |
| 0.9 | 0.4826≤P≤4.137 | T=log(p/5.1738)×7.42-17.78 |
| | 4.137≤P≤27.58 | T=log(p/0.4382)×4.086-17.78 |
| 0.8 | 0.5516≤P≤5.516 | T=log(p/6.9808)×7.5896-17.78 |
| | 5.516≤P≤27.58 | T=log(p/0.4608)×4.781-17.78 |

| | | |
|---|---|---|
| 0.7 | 0.6895≤P≤6.895 | T=log(p/9.4891)×7.8027-17.78 |
| | 6.895≤P≤27.58 | T=log(p/0.5338)×4.7934-17.78 |
| 0.6 | 1.03425≤P≤10.3425 | T=log(p/16.5738)×8.28-17.78 |
| | 10.3425≤P≤27.58 | T=log(p/0.199)×4.174-17.78 |
| 0.55 | 2.758≤P≤12.06625 | T=log(p/57.9679)×9.513-17.78 |
| | 12.06625≤P≤27.58 | T=log(p/19.0849)×7.20565-17.78 |
| G is between $r_{g1}$ and $r_{g2}$ （Using the interpolation method） | $T=T_1-(T_2-T_1)\times(r_{g1}-r_g)/(r_{g1}-r_{g2})$<br>（1）、$r_g$—The relative density of gas， $r_{g1}< r_g< r_{g2}$<br>（2）、$T_1$、$T_2$—The temperature to formation hydrate when the pressure has be known and the relative density of gas were $r_{g1}$ and $r_{g2}$ | |

Ⅳ calculation example

There are gas composition and production data of two gas well in SuQiao gas storage, shown as table 3 and table 4.

Table 3 the composition of natural gas and the proportion

| No of the well | $CH_4$ /% | $C_2H_6$ /% | $C_3H_8$ /% | $C_4H_{10}$ /% | $N_2$ /% | $CO_2$ /% | $H_2S$ /% | others /% |
|---|---|---|---|---|---|---|---|---|
| 1 | 78.40 | 6.00 | 3.60 | 2.40 | 9.40 | 0.20 | 0.00 | 0.00 |
| 2 | 96.96 | 0.18 | 0.04 | 0.00 | 0.64 | 2.18 | 0.00 | 0.00 |

Table 4 production data

| Basic data | No.1 well | No.2 well |
|---|---|---|
| Formation temperature of the bottom hole/℃ | 120 | 105 |
| Flowing bottom hole pressure/MPa | 40 | 31 |
| Well depth/m | 4728 | 3708.8 |
| Geothermal gradient/(℃/m) | 0.025 | 0.0298 |
| Outer diameter of casing/m | 0.177 8 | 0.177 8 |
| Diameter of the well/m | 0.24 | 0.24 |

| | | |
|---|---|---|
| Inside diameter of tubing/m | 0.073 | 0.073 |
| Gas viscosity/(mPa·s) | 0.02 | 0.018 |
| Relative density | 0.63 | 0.5767 |
| Water production/($m^3$/d) | 13.541 | 11.342 |
| Tube wall roughness/m | $4.57\times10^{-5}$ | $4.57\times10^{-5}$ |
| Formation thermal conductivity /(W/(m·K)) | 1.717 | 2.2 |
| Formation thermal diffusion coefficient/($m^2$/d) | 0.002 65 | 0.00864 |
| Volumetric gas flow/($m^3$/d) | 97200 | 60000 |

Deal with these data with programming, we can get the temperature、pressure at the wellhead place and hydrate formation interval etc. Listed these data and reference data in table 5 and table 6 and compared them.

Table 5 data compare in No 1 well

| parameter | Calculate predictive value | Measured values | error |
|---|---|---|---|
| Wellhead pressure/MPa | 30.80 | 28.56 | 7.27% |
| Wellhead temperature/℃ | 33.22 | 32.45 | 2.3% |
| Location for hydrate formation/m | - | - | - |

Table 6 data compare in No 2 well

| parameter | Calculate predictive value | Measured values | error |
|---|---|---|---|
| Wellhead pressure /MPa | 25.40 | 24.15 | 4.9% |
| Wellhead temperature /℃ | 16.61 | 15.98 | 3.8% |
| Location for hydrate formation /m | 200-300 | 225 | - |

Comparison results show that the maximum error for wellhead pressure is 7.27% and the maximum error for wellhead temperature is 3.8%. Predicted results were very closed to the measured data, it’s can meet the requirements of industrial production accuracy totally.

## Ⅴconclusion

1). The article used the pressure-temperature coupling analysis model, comprehensive consideration the mutual influence between the pressure and temperature, the calculation results were in conformity with actual.

2). The P-T figure method that we used to predict the formation of hydrate, balanced security and the calculation accuracy, it could meet the engineering requirements.

3). The formation of gas hydrate are influenced by many factors. Among them, temperature, pressure, gas composition and the activity of aqueous solution has a more bigger influence.

4) When the composition of the gas and other conditions had been determinate, it's temperature and pressure in the pipeline decided if formation hydrate. More higher pressure, more lower temperature, it will be more easier to form hydrate.

5) The distribution of pressure and temperature in wellbore were influenced by natural gas production, pipeline diameter and surface properties, well depth and casing program, reservoir pressure and temperature, the composition of well stream and geothermal gradient etc.

6). We can take measures such as reduce pressure, improvement temperature, change the nature of the aqueous solution to prevent the formation of hydrate. Downhole choke pressure drop[8], heating and heat preservation, production control[9], coating hydrophobic layer on tubing wall and adding chemical inhibitors[10] [11] are the commonly measures that we used to prevent the formation of hydrate.

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