Comparison and adaptability evaluation of formation pressure calculation methods and computer simulation in Jingbian gas field

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Abstract. In the process of oilfield development, formation pressure is an essential parameter for evaluating oilfield development effect, calculating dynamic geological reserves, conducting daily dynamic analysis of oil and water Wells and predicting oilfield performance. The pressure recovery time of conventional gas well after shut-in is very long, and it is difficult to effectively carry out targeted implementation due to the influence of gas field external supply task. In this paper, based on the actual data of Jingbian gas field, through the comparison of several calculation methods of formation pressure, the best method to calculate formation pressure is comprehensively screened out. The results show that: ① For a single method, the accuracy of the method from high to low is the well head casing pressure conversion method, the pressure drop curve method, the binomial productivity equation method, and the quasi-steady state mathematical model method. ② The absolute error of multi-method comprehensive calculation method is 0.9MPa, which is far less than the average absolute error directly calculated by one method. The multi-method comprehensive calculation method is reliable when applied to the formation pressure evaluation of typical gas Wells in Jingbian gas field, which lacks data.

Keywords: Jingbian gas field, formation pressure, calculation method, single method, multiple methods, data.

1. Introduction
The formation pressure of gas well is an essential basic data for calculating geological reserves, determining formation characteristics, understanding the present and future dynamics of oil and gas reservoirs. It plays a very important role in improving the production degree of reserves, the overall development and deployment of oil reservoirs, and adjusting the working system of pumping well. [1-5]
The formation pressure can be obtained by directly measuring the stable pressure after shut-in with down hole pressure gauge, or by using unstable well test method and through appropriate mathematical processing. Many scholars have also proposed many methods in this regard [6-11]. In the actual development process, it is impossible to turn off the down hole manometer frequently to measure the formation pressure, and shut in the well for a long time to test the pressure recovery, which makes it necessary to directly use the production data to obtain the formation pressure values of the gas well in different periods. [12-15] Combined with the actual situation of Jingbian gas field, this paper compares and analyzes the calculation method of single formation pressure, and further studies the adaptability of the evaluation method of formation pressure with the combination of multiple methods.

2. Single method for calculating formation pressure

In this paper, four typical single methods for formation pressure calculation are selected, which are the constant volume closed gas reservoir method, the well head casing pressure conversion method, the quasi-steady state method and the binomial productivity equation method. Each calculation method and main calculation formula are shown in Table 1.

| Method                              | Formula to calculate                                                                 |
|-------------------------------------|--------------------------------------------------------------------------------------|
| Constant volume closed gas reservoir| \( G_p B_p = G( B_p - B_w) + GB \frac{C_s S_w + C_p \Delta p}{1 - S_w} \)               |
| Well head casing pressure conversion| \( D = AP_{sh} + B \) \( P_i = P_{sh} + D \times H \)                                  |
| Quasi steady state method           | \( P_i = 6 \times 10^{-8} G_p^2 - 0.0013 G_p + 24.94 \)                              |
| Binomial productivity equation method| \( P_i = \sqrt{4q + Bq^2 + \frac{P_{wf}^2}{1 - S_w}} \) \( A = 1108.8q \frac{1.235}{1.5607} \) \( B = 98.655q \frac{1}{1 - S_w} \) |

Taking the pressure drop curve method (constant volume gas reservoir) as an example, the comparison between the calculated formation pressure and the actual shut-in pressure measurement results is shown in Table 2.

| Well no. | Casing pressure | Z | Cumulative water production | Water-air ratio | Measured pressure | Calculation results | Relative error | Absolute error |
|---------|----------------|---|----------------------------|----------------|------------------|---------------------|---------------|---------------|
|         | MPA            |   | 10^3m^3                    | 10^4m^3/10^8m^3| MPA              | MPA                | %             | MPA           |
| G10-13  | 6.8            | 0.9434 | 30402.589                  | 0.1035         | 11.14            | 9.52               | 14.5          | 1.62          |
| G10-14  | 7.8            | 0.9478 | 71548.9215                 | 0.0792         | 9.84             | 6.15               | 37.5          | 3.69          |
| G10-15  | 20.1           | 0.9679 | 2663.9489                  | 0.6542         | 25.09            | 14.95              | 40.4          | 10.14         |
| G10-18  | 18.89          | 0.93861 | 6086.6263                 | 0.1139         | 13.23            | 10.82              | 18.2          | 2.41          |
| G10-9   | 8              | 0.94845 | 17335.7654                | 0.1991         | 10.38            | 8.63               | 16.9          | 1.75          |
|         | The average    |     |                           |                |                  |                    | 25.5          | 3.92          |
3. Comparison of formation pressure calculation results by single method

Four typical single methods were used for the calculation, and the relationship between the frequency of the calculated results and the relative error was shown in Fig. 1-4. The material balance method has a very high accuracy in calculating formation pressure. Based on rich measured data, the accurate pressure drop curve relationship is established, and the evaluation results are very reliable. However, due to the limitations of field factors such as low porosity and low permeability shut-in and long recovery time, large-scale application cannot be realized. The quasi-steady state mathematical model is suitable for gas Wells with stable working system, and requires accurate control of the quasi-steady state critical pressure, and requires long production time (high recovery degree) of gas Wells, so it is not suitable for early development Wells in tight and low permeability Jingbian gas field.

![Figure 1. Constant volume sealed gas reservoir](image1)

![Figure 2. Wellhead casing pressure](image2)

![Figure 3. The quasi steady state method](image3)

![Figure 4. Binomial productivity method](image4)

The improved wellhead pressure conversion method is simple and convenient to evaluate the formation pressure, but there are many types of pressure drop curves in the Sudong block. In the actual evaluation, the curve shape should be judged first and the appropriate curve type should be selected to improve the evaluation accuracy.

4. Multiple-method calculation of formation pressure

126 tone of well data of typical Jingbian-Yanshuiguang pipeline gas field, according to the calculation of formation pressure required data (the original formation pressure and open flow potential and temperament analysis data, etc.) to sorting and statistics, it can get 126 typical gas Wells in the G8-8 Wells 65 Wells, such as lack of bottom hole flowing pressure measured data, the Shan 90 Wells 84 Wells, such as lack of quality analysis data, Thirty-one Wells, such as well G3-10A, lack measured formation pressure data. In addition, 85 Wells, including G1-10, have complete data to directly evaluate formation pressure using a calculation method. Of the remaining 30 Wells, 17 Wells, including G1-16B, lack original formation pressure data, and 14 Wells, including G9-18, lack open flow data. Four Wells, such as Well G14-9, were missing two parameters of original formation
pressure and dynamic reserves, while 13 Wells, such as Well Jing70-18, were missing three important parameters of original formation pressure, dynamic reserves and open flow.

4.1. The dynamic reserve calculation method is combined with the pressure drop method

4.1.1. The dynamic reserve calculation method is combined with the pressure drop method. The basic idea of this method is to assume that under the condition of a certain controlled reserves, the material balance equation of gas reservoir and the binomial gas production equation of gas well are solved simultaneously, and then the production curve of gas well is calculated, which matches with the actual production curve of gas production, and finally the relevant parameters are determined.

Assuming the stable well test productivity equation combined with the gas reservoir material balance equation:

\[
P_i = \frac{P_i}{Z_i} \left( 1 - \frac{G_p}{G} \right)
\]

The specific solving steps are as follows:

1. First assume a dynamic reserve \( G \);
2. Read production \( q \) and cumulative gas production \( G_p \) at different time from the gas production curve;
3. Substituting \( G \) value and \( q \) and \( G_p \) values at different times into the above equation, the \( P_{wf} \) value of bottom hole flow pressure at the corresponding time is calculated, and compared with the measured \( P_{wf} \) value. If the calculated value is close to the actual value, it indicates that \( G \) value is correct, and this value is the desired controlled gas well reserves. If the calculated \( P_{wf} \) is higher than the actual \( P_{wf} \), it means that \( G \) is too large; otherwise, it means that \( G \) is too small, as shown in Figure 5.
4. If we use \( G \) and \( P_{WF} \) and \( G_p \) values of different time to calculate the corresponding \( Q \) value to fit the yield curve, we will get the same effect.

![Figure 5. Gas production curve of well G11-14.](image)

![Figure 6. Schematic diagram of solving geological reserves by material balance pressure drop method.](image)

As can be seen from the above figure, the calculated \( P_{wf} \) is slightly lower than the measured \( P_{wf} \), so it can be concluded that the assumed dynamic reserve value \( G \) is slightly lower than the actual dynamic reserve value.

4.1.2. Expand the material balance method. For closed gas reservoirs with constant volume, by deformation of the formula, it is obvious that regression can be carried out to solve the gas reservoir or gas well controlled geological reserves \( G \) according to the formation pressure at different stages and the corresponding cumulative gas production. As shown in Figure 6.
Among them:

\[
G = \frac{G_p}{1 - \frac{P \cdot Z_i}{Z \cdot P_i}}
\]  

(2)

4.1.3. The yield accumulation method is combined with the pressure drop curve method considering the water produced. (1) Collect the data of cumulative gas production \(G_p\) and production time \(t\) of a single well; (2) Calculate the product of cumulative gas production and production time \(G_p \cdot t\); (3) Draw the relationship curve between \(G_p \cdot t\) factor and production time \(t\); The linear segment at the end of the curve is fitted and the fitting relation is written. (4) Slope \(A\) of the fitting curve is single well dynamic reserves \(G\).

Figure 7. Time curve of cumulative gas production  
Figure 8. \(G_p \cdot t\)–\(t\) curve of well G11-14

Compared with the previous two methods, the dynamic reserve calculated by this method is smaller and the error is slightly larger.

4.2. Calculation of open flow and formation pressure

4.2.1. The empirical formula method of open flow combined with the binomial method of steady-point productivity. If there is no gas well with open flow data, the open flow of gas well can be obtained by the empirical relation between the open flow of gas well in Jingbian Gas Field and the binomial productivity equation coefficient, and by combining the binomial method of steady point productivity to get the productivity coefficient \(A\) and \(B\).

4.2.2. The one-point method is combined with the binomial productivity equation for gas well stability. The binomial productivity equation of gas well stability is:

\[
P_i^2 - P_{wi}^2 = Aq_x^2 + Bq_x^2
\]  

(3)

When the bottom hole flow pressure is one atmosphere, there are:

\[
P_i^2 - (0.101)^2 = Aq_{AOF}^2 + Bq_{AOF}^2
\]  

(4)

Divide the two equations, and we get:

\[
\frac{P_i^2 - P_{wi}^2}{P_i^2} = \frac{Aq_x^2 + Bq_x^2}{Aq_{AOF}^2 + Bq_{AOF}^2}
\]  

(5)
The one-point method formula for open flow is obtained:

\[ q_{AOF} = \frac{2(1-\alpha)q_s}{\alpha \left[ 1 + 4 \left( \frac{1-\alpha}{\alpha^2} \right) \left( \frac{p_i^2 - p_{sat}^2}{p_i^2} \right) - 1 \right]} \]  

(6)

The one-point formula for Jingbian Gas Field is:

\[ q_{AOF} = \frac{1.77q_s}{\sqrt{1 + 6.69 \left( \frac{p_i^2 - p_{sat}^2}{p_i^2} \right) - 1}} \]  

(7)

4.3. Initial formation pressure and formation pressure calculation

The original formation pressure can be determined by collating well daily production, bottom hole flow pressure, and cumulative gas production data at a given time.

Table 3. Relation table of \( P_r/Z \) and cumulative production of Shan 81 well.

| The formation pressure is \( P_r/MPa \) | Deviation factor \( Z \) | \( P_r/Z \) | Cumulative production \( G_p/10^4m^3 \) |
|--------------------------------------|-----------------|-----------------|-----------------|
| 23.33 | 0.94314 | 24.74 | 4831.696 |
| 19.29 | 0.94366 | 20.44 | 9739.2038 |
| 15.74 | 0.94358 | 16.68 | 10774.4564 |
| 14.81 | 0.94353 | 15.7 | 11490.3913 |
| 11.88 | 0.94332 | 12.59 | 12312.8635 |

Data fitting shows that the relationship between \( P_r/Z \) and cumulative production \( G_p \) is:

\[ \frac{P_r}{Z} = -0.0017G_p + 35.67 \]  

(8)

5. Comparison and analysis of different calculation results

The comprehensive calculation results of the original formation pressure, dynamic reserves, open flow and other parameters of 30 gas Wells by various methods are shown in the table below. It is reliable to apply the multi-method comprehensive calculation method to the formation pressure evaluation of typical gas Wells in Jingbian Gas field, which lacks data.

Table 4. The results are calculated by various methods.

| Well no. | Actual pressure MPa | Calculated results Mpa | Relative error % | Absolute Error Mpa |
|----------|---------------------|------------------------|------------------|--------------------|
| G4-6     | 14.05               | 13.05                  | 7.12             | 1.00               |
| G4-6C    | 18.67               | 18.98                  | 1.67             | 0.31               |
| G9-19    | 11.86               | 11.77                  | 0.77             | 0.09               |
| Shan161  | 29.73               | 30.33                  | 2.03             | 0.60               |
| Shan168  | 21.94               | 23.16                  | 5.57             | 1.22               |

The average: 3.432, 0.644

6. Conclusion

For a single method, its accuracy from high to low is the well head casing pressure conversion method, pressure drop curve method, binomial productivity equation method, and quasi-steady state mathematical model method.
The absolute error of the multi-method comprehensive calculation method is 0.9MPa, which is far less than the average absolute error directly calculated by one method. The multi-method comprehensive calculation method is reliable when applied to the formation pressure evaluation of typical gas Wells in Jingbian gas field, which lacks data.

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