# The Research of Pinpoint Formation Pressure Test Method and in the Application of Jingbian Gasfield

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***Abstract*—Pressure is a essential factor to be determined in gas field development. How to obtain the accurate current formation pressure is a difficulty encountered in developing low permeability gas reservoirs like Jingbian Gasfield. For this kind of low permeability gas reservoir, in the premise of finishing the production task, to do the least work to meet the need of the development of research is a necessary solved problem in the gas reservoir development. In allusion to these problems, the pinpoint formation pressure test method is adopted to calculate the current formation pressure of single well in this file. Conclusions obtained:1)The calculating gas well current formation pressure method is a feasible way to solve those problems.2)Using the static pressure test data to calculate gas well current formation pressure is suitable for Jingbian Gasfield, according to the comparison in this essay. 3)The error analysis has been done by using the static pressure data and long-term (shut-in time is more than 80 days) shut-in data, which can also be used to calculate formation pressure. The reasonable range of error control of three kinds of well can be obtained by deducing. By judging the range, we can determine whether the obtained calculating formation pressure test result is correct or not.**

***Index Terms*—low permeability gas reservoir, formation pressure, pinpoint formation pressure test method, the error analysis, Jingbian Gasfield**

## I. Introduction

On the one hand, Jingbian Gasfield has the characteristics of low permeability, low abundance, thin reservoir, obvious heterogeneity, large production well interval (generally>2.5km) and it takes several months to reach stability after pressure build-up upon re-startup. On the other hand, Jingbian Gasfield has high daily gas production rate in recent years and it has rare chance to shut down well when field test and pressure measuring have to be done. All of these factors contribute to difficulties to measure current formation pressure. So, using a feasible and accurate method to get gas well current formation pressure is necessary [1]-[7].

## II. Use Build-up Test Method to Calculate the Formation Pressure of Single Well

Intercept method, Ho's method, Hasan and Kabir method use build-up test data in fillup period to calculate average formation pressure. These methods need the least related data to calculate the accurate average formation pressure. These methods do not need other parameters except the build-up test data. The conventional method requires the formation parameters (k, h, Φ), fluid parameters ($\mu_g$, Ct), well parameters ($r_w$, A), especially drainable area(A), however, it is difficult for heterogeneous reservoir. Permeability(k) is more difficult to be determined for low-permeability oil/gas reservoir than other kinds of reservoir, therefore, these three methods are more simple [8].

### *A. Use Intercept Method to Calculate a Gas Well'S Formation Pressure*

Analysis of the build-up curve Horner method can be expressed as:

$$P_{ws} = P_i - m\lg\frac{t_p + \Delta t}{\Delta t} \quad (1)$$

(1), $P_{ws}$—bottom build-up pressure, MPa;
$P_i$—initial formation pressure, MPa;
$t_p$—conversion of production time before the gas well shut-in, h;
$\Delta t$ —shut in time, h;
where:

$$m = \frac{2.12\times10^{-3} q_g \mu_g B_g}{kh}$$

After deriving, arranging, we can get:

$$p_{ws} = \bar{p}_r + b\cdot\frac{\Delta p}{\Delta t} \quad (2)$$

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(2), $\bar{p}_r$ —average reservoir pressure, MPa;

$\Delta p$ —the pressure difference, MPa;

$t_p$—conversion of production time before the gas well shut-in, h;

where:

$$b = -\frac{t_p}{\alpha + 1}$$

From (2), we can take the shut well recovery pressure ( $p_{ws}$ ) as y-coordinate and take $\frac{\Delta p}{\Delta t}$ as the abscissa in ordinary graph paper respectively. Then we can make a relationship chart of $p_{ws}$ and $\frac{\Delta p}{\Delta t}$ and get a straight line. When the line is extrapolated to $\frac{\Delta t}{\Delta p} = 0$, the intercept at ordinate is oil/gas drainable area or average reservoir pressure in gas bearing area.

Intercept method is suitable for the low, medium and high permeability regardless of length of production time of oil/gas Wells.

*B. Use Ho's Method to Calculate a Single Well Formation Pressure*

Based on Horner equation, the following formula is gotten after complex mathematics' derivation:

$$p_{ws} = p_i - \frac{m}{2.303}(\lg\alpha - 2) - \frac{4m(t_p + \Delta t)}{2.303[t_p(\alpha+1)\Delta t]} \quad (3)$$

After a series of transformations and simplification,

$$\frac{\Delta t}{p_{ws} - p_{wf}} = D\Delta t + B \quad (4)$$

(4), $P_{wf}$—bottom flow pressure, MPa;

where:

$$D = -b/c,\ B = -b^2/c,\ b = \frac{t_p}{\alpha+1},$$
$$c = \frac{4mt_p}{2.303(\alpha+1)}$$

(4) divides by $\Delta t$ in both sides, when $\Delta t \to \infty$, $p_{ws} \to \bar{p}_r$,

$$\bar{p}_r = p_{wf} + \frac{1}{D} \quad (5)$$

(5) is the formula of calculating the average formation pressure. According to (4) we conduct linear regression analysis of the pressure recovery data and obtain the slope D and the sum of reciprocal of slope. Meanwhile oil/gas well bottom hole flowing pressure is the average formation pressure.

This method can use any phase of the data of recover pressure to calculate the average formation pressure. The result is at the same precision and do not need to check the theory chart of the dimensionless pressure and the dimensionless time. It needs only a linear regression analysis to seek the average formation pressure.

*C. Use Hasan and Kabir Method to Calculate a Single Well Formation Pressure*

In the infinite formational linear flow stage, after a transition phase, this phase is replaced by the plane radial flow phase. Pressure recovery method of this stage can be used by the expression of Horner equation:

$$p_{ws}^2 = p_i^2 - 4.242\times10^{-3}\frac{q_g\mu_g ZTP_{sc}}{khT_{sc}}\lg\frac{t_p+\Delta t}{\Delta t} \quad (6)$$

(6),$q_g$—gas well production at ground standard conditions, $m^3$/d;

$\mu_g$—viscosity of formation gas, Pa•s;

Z—gas deviation factor;

T—formation absolute temperature, K;

$P_{sc}$—surface gage pressure(0.101), MPa;

$T_{sc}$—surface normative absolute temperature (293), K;

h—formation effective thickness, m;

k—formation effective permeability, $\mu m^2$;

Based on Horner equation, after a series of assumptions:

$$p_{ws}^2 = a + \frac{c}{\Delta t + b} \quad (7)$$

where:

$$a = p_i^2 - \frac{m}{2.303}(\ln\alpha - 2);\ b = \frac{t_p}{\alpha+1};\ c = -\frac{1.737mt_p}{\alpha+1}$$

We can see from the (7), bottom recovery pressure will gradually approach to average formation pressure, there are:

$$\bar{p}_r = \sqrt{a} \quad (8)$$

$$b = \frac{\Delta t_1\Delta t_2 + \Delta t_2\Delta t_3 - 2\Delta t_1\Delta t_3}{\Delta t_1 + \Delta t_3 - 2\Delta t_2} \quad (9)$$

Putting the value of b in (7), we can draw the relation curve of $p_{ws}^2$ and $\frac{1}{\Delta t + b}$ with recovery pressure curve by the continued stream segment data and can get straight line equation after the regression of the curve. Then we put the linear intercept in (8) to get $\bar{p}_r$ [9].

Table I shows that using build-up test data can obtain gas well formation pressure through the above methods and get current formation pressure through the pressure drop equation.

The results show that using the three methods to calculate formation pressure of the gas well in test period is more accurate, and can completely to use test period average formation pressure to get current formation pressure.

## III. Use Manometric Data Obtained to Calculate a Formation Pressure of Single Well

Because of short test time measuring static pressure in shutting well period , use bottom hole pressure instead of formation pressure to calculate the formation pressure will enlarge the error. This section uses build-up data and static pressure test data to obtain formation pressure. Table II shows the classification of 9 wells.

TABLE I. USING BUILD-UP TEST DATA TO OBTAIN FORMATION PRESSURE OF GAS WELL

| Well number | Formation pressure in the test period (MPa) | | | | Formation pressure at present (MPa) |
|---|---|---|---|---|---|
| | Intercept method | Ho's method | Hasan-Kabir method | Average | |
| G10-17 | 26.47 | 26.46 | 26.65 | 26.53 | 12.59 |
| G52-17 | 28.05 | 28.07 | 28.04 | 28.05 | 19.46 |
| G43-6 | 28.58 | 28.64 | 28.53 | 28.59 | 24.30 |
| G32-9 | 30.83 | 30.77 | 30.82 | 30.81 | 24.50 |
| G9-8 | 24.46 | 24.36 | 22.22 | 23.68 | 13.16 |
| G32-4 | 25.44 | 25.40 | 25.32 | 25.39 | 16.22 |

TABLE II. CLASSIFICATION TAB OF THE 9 WELLS

| Classification | | Well number | Open flow capacity of test gas ($10^4m^3$/d) | Stable production ($10^4m^3$/d) |
|---|---|---|---|---|
| Class 1 high output well | $q_{AOF}$>100 q>15 | G24-1 | 113 | 21.2 |
| | | S 122 | 148 | 21.4 |
| | | G29-3 | 40 | 21.3 |
| | | G18-7 | 29 | 16.3 |
| | | G15-2 | 39 | 18.83 |
| Class 2 Medium output well | 50<$q_{AOF}$<100 5<q<15 | G33-3 | 63 | 13.5 |
| | | G48-12 | 21 | 9.1 |
| Class 3 low output well | $q_{AOF}$<50 q<5 | S 3 | 46 | 5.2 |
| | | S 81 | 22 | |

According to the open flow capacity of every well in testing gas period and daily gas production rate, the 9 wells have been clarified into 3 class.

Analyzing statistical data and fitting the relationship of three kinds of wells between

“ $\frac{\text{bottom hole pressure in different time}}{\text{formation pressure in period of measuring static pressure}} = \text{restore degree}$ ” and time in build-up period, then getting the formula between "restore degree" and the time.

Classify the other gas wells, which have been conducted the static pressure test, by the same method and fit "restore degree" with time to get the formula. We use the formula to calculate formation pressure of these wells during the static pressure test and set up the pressure drop equations to get the current formation pressure of wells.

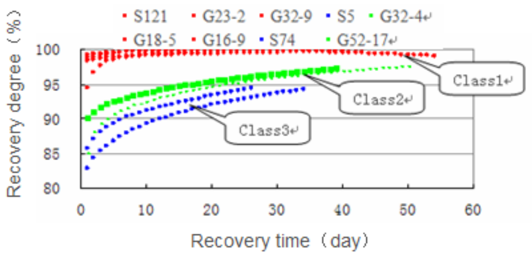


Figure 1. The scatter plot of recovery degree changes with time of bottom static pressure of three kings of wells.

As Fig. 1 shows, the scatter plot related to the ratio of corresponding static pressure in different time and formation pressure at that time in build-up test period has been drew as the following figure shows.

Class 1:

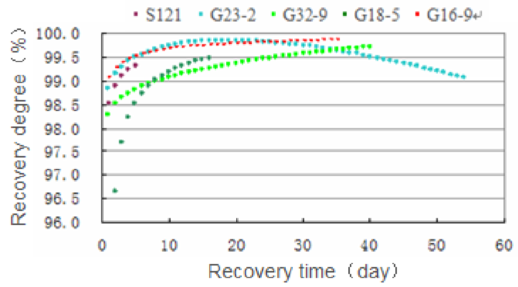


Figure 2(a). The scatter plot of recovery degree changes with time of bottom static pressure of class 1.

Class 2:

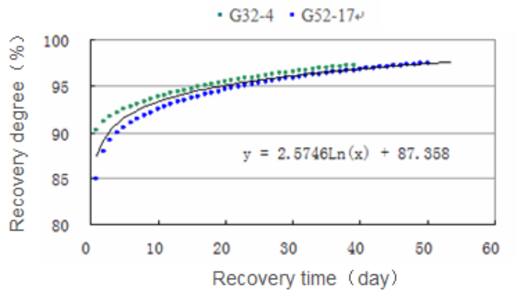


Figure 2(b). Tthe scatter plot of recovery degree changes with time of bottom static pressure of class 2.

Class 3:

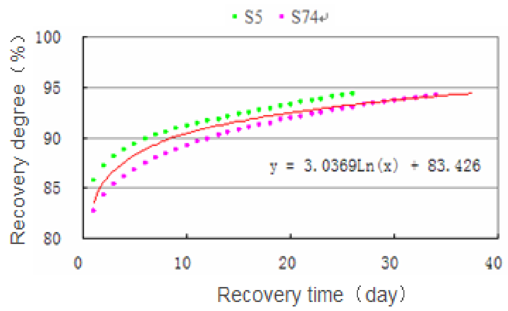


Figure 2(c). The scatter plot of recovery degree changes with time of bottom static pressure of class 3

As Fig. 2 shows, the scatter plot related to recovery degree changes with time of three kinds of wells respectively has been drew.

As can be seen from Fig. 2, in 20 to 30 days after well shut-in, the bottom hole static pressure can restore to more than 99% of the formation pressure at that time for class 1, and the interference from neighboring well will lead to a slight drop of their bottom hole static pressure in 30 days. So, 20 days is enough to shut-in this kind of well in tests. In 30 to 40 days later after well shut-in of class 2, the bottom hole static pressure can recover to more than 95% of the formation pressure; In 30 to 40 days later after well shut-in of class 3, the bottom hole static pressure can recover to more than 93% of the formation pressure. After the class 2 and class 3 wells are both shut-in, in order to show the relationship of bottom hole static pressure and time, these two kinds of well data will do the scatter plot data fit, which is related to these two class wells' changes of static pressure and formation pressure with time. Fit formulas are shown in Fig. 2 (b) and Fig. 2 (c).

TABLE III. USE STATIC PRESSURE TEST DATA TO OBTAIN CURRENT FORMATION PRESSURE

| Well number | Classification | Test date (year-month-day) | Recovery time (day) | Static pressure (MPa) | Formation pressure at that time (MPa) | Formation pressure at present (2015.06) (MPa) |
|---|---|---|---|---|---|---|
| G16-14 | 1 | 2011-5-6 | 30 | 23.33 | 23.56 | 22.07 |
| | | 2011-6-1 | 60 | 23.83 | 24.07 | |
| | | 2012-5-28 | 60 | 22.86 | 23.09 | |
| G14-5B | 2 | 2012-9-11 | 60 | 27.99 | 28.68 | 27.60 |
| G14-4A | 3 | 2012-6-13 | 45 | 23.23 | 24.74 | 24.42 |

As Table III shows, according to the above relations of three kinds of well ,for the other wells especially these which have been conducted static pressure test, the data fit and calculation of formation pressure will be conducted during static pressure test. Then set up the pressure drop equation of the well to get the single well's present formation pressure.

## IV. THE METHOD TO DETERMINE SINGLE WELL FORMATION PRESSURE AND THE EVALUATION OF METHOD

During the period of using the static pressure test data to obtain the well current formation pressure, a part of wells have suffered long-term shut-in while are still in production, according to the calculation of bottom hole static pressure after well shut-in, and calculated result instead of that time's formation pressure can be used to set up the pressure drop equation of the well, which can obtain the single well current formation pressure. Table IV shows the current formation pressure [10]-[13].

TABLE IV. CURRENT FORMATION PRESSURE TAB

| Well number | Well shut-in end date (year-month-day) | Well shut-in days (days) | Formation pressure at that time (MPa) | Current formation pressure (2015.01) (MPa) |
|---|---|---|---|---|
| G12-16 | 2012-11-26 | 127 | 29.92 | 26.56 |
| G13-16 | 2012-11-26 | 127 | 28.83 | 18.11 |
| G14-10 | 2013-6-30 | 94 | 21.33 | 17.84 |
| G14-11 | 2013-6-30 | 89 | 19.67 | 16.18 |
| G14-3 | 2012-10-4 | 335 | 28.19 | 24.10 |
| G14-6 | 2012-8-31 | 94 | 15.07 | 13.96 |
| G14-8 | 2013-11-16 | 167 | 15.29 | 14.36 |
| G15-10 | 2012-6-30 | 89 | 17.19 | 14.71 |

Table V shows: the error of class 1 well is controlled under the range of ±4% ; the error of class 2 well is controlled under the range of ±7%; the error of class 3 well is controlled under the range of ±7%; The above result proves that the method is accurate.

Comparing the above results with current formation pressure obtained by static pressure test data, we can see that the two kinds of results are approximate ,moreover, we can deduce that the current formation pressure obtained by the static pressure test data is reasonable. For these two class wells, the average value of two methods' results can be used as current formation pressure.

TABLE V. COMPARISON OF THE CALCULATED RESULTS

| Well number /Classification | Formation pressure calculation results (MPa) | | | Current formation pressure finally (MPa) | The error of [(P1/P2)-1]*% (%) |
|---|---|---|---|---|---|
| | Static pressure data calculatin results (P1) | Long-term shut-in data calculation results (P2) | Average (MPa) | | |
| G35-9 (1) | 13.83 | 13.57 | 13.70 | 13.70 | 1.92 |
| G9-9 (1) | 16.61 | 17.04 | 16.82 | 16.82 | -2.52 |
| G11-10 (1) | 20.54 | 19.98 | 20.26 | 20.26 | 2.82 |
| G14-6 (1) | 15.17 | 15.56 | 15.37 | 15.37 | -2.51 |
| G15-12 (1) | 18.43 | 17.56 | 17.99 | 17.99 | 4.94 |
| G23-18 (2) | 21.63 | 20.71 | 21.17 | 21.17 | 4.43 |
| G0-9 (2) | 23.57 | 22.19 | 22.88 | 22.88 | 6.23 |
| G5-11 (2) | 22.85 | 21.95 | 22.40 | 22.40 | 4.11 |
| G08-11 (2) | 26.97 | 25.89 | 26.43 | 26.43 | 4.18 |
| S193 (2) | 24.30 | 23.38 | 23.84 | 23.84 | 3.97 |
| G16-18 (3) | 23.26 | 24.13 | 23.70 | 23.70 | -3.57 |
| G35-5 (3) | 20.33 | 19.207 | 19.77 | 19.77 | 5.90 |
| G14-10 (3) | 19.04 | 17.84 | 18.44 | 18.44 | 6.74 |
| G6-10 (3) | 18.46 | 17.26 | 17.86 | 17.86 | 6.94 |
| G48-15 (3) | 26.31 | 26.74 | 26.52 | 26.52 | -1.64 |

## V. CONCLUSION

(1) The pinpoint formation pressure test method being used to calculate current formation pressure is a feasible way.

(2) Comparisons show that using the static pressure test data to calculate gas well current formation pressure is suitable for the application of JingBian Gasfield.

(3) Use the static pressure data and long-term shut-in data calculation to do the error analysis and obtain the error range: that the error of class 1 well is controlled under the range of ±4% or less is accurate; that the error of class 2 well is controlled under the range of ±7% or less is accurate; that the error of class 3 well is controlled under the range of ±7% or less is accurate. The current formation pressure by the static pressure test data obtained is reasonable and take the average of two kinds of methods as the current formation pressure value. Do the error analysis by using the static pressure data and long-term (shut-in time is more than 80 days) shut-in data which can be used to calculate formation pressure. Then deduce to obtain the reasonable range of error control of three kinds of well. To judge of this range, we can test whether the calculating formation pressure test result obtained is correct.

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