Determination of Reservoir Parameters by Pressure Build-Up Curve, Recorded after Prolonged Well Development

E E Levitina1, M I Zaboeva1, I A Kovalev1

1Industrial University of Tyumen, 38, Volodarskogo-street, Tyumen, 625000, Russian Federation

E-mail: 934964@mail.ru

Abstract. The article discusses the determination of the filtration parameters of the formation such as hydraulic conductivity, permeability, piezoconductivity using the data obtained during the hydrodynamic study of the well. The pressure build-up curve recorded as a result of the study is processed by the tangential method and also allows one to assess the degree of contamination of the bottom-hole part of the formation and calculate the actual and potential well production rate. The data obtained are of great importance for making operational decisions in the regulation and control of the development of oil fields.

1. Introduction
Investigation of wells with a transient filtration regime involves studying the dependence of the change in bottomhole pressure on time during the transition from one stationary state to another. The resulting relationship between the change in pressure at the bottom of the well with time is called the pressure build-up curve (PBU curve).

The purpose of the study is to assess the hydrodynamic perfection of the well, filtration parameters and heterogeneity of reservoir properties based on the obtained and processed PBU curve.

2. Methods
In oilfield practice, when processing PBU curve, a simplified solution of the basic differential equation of the elastic regime for a point source-runoff in an infinite reservoir is used. The solution to this equation is a linear relationship between the change in pressure and the logarithm of time. In this case, the heterogeneity of the bottomhole zone is taken into account using the skin-effect indicator or the reduced radius of the well.

Let us consider the case of pressure build-up treatment, when the pressure build-up curves are recorded after the well is operated for a long time $T$, which is much longer than the pressure build-up time $t (T >> t)$. Determination of reservoir parameters in this case is obtained by drawing a tangent to the last points of the pressure build-up, built in semi-logarithmic coordinates.

So, the initial equation for calculating the reservoir parameters according to the pressure build-up curve, recorded after prolonged well development, is the expression

$$P_b = P_r - 0,183 \frac{q \mu}{kh} \lg \frac{2,25 \chi t}{r_w^2},$$  \hspace{1cm} (1)
where $P_b$ - bottomhole pressure, $Pa$; $P_r$ - reservoir pressure, $Pa$; $q$ - well flow rate at the bottomhole, $m^3/s$; $r_w$ - the radius of the well, $m$; $h$ - formation thickness, $m$; $k$ - permeability, $m^2$; $\chi$ - piezoconductivity, $m^2/s$; $\mu$ - fluid viscosity, $Pa\cdot s$; $t$ - is the recording time of the PBU curve, $s$.

We write the previous equation in the form:

$$
\Delta P(t) = 0,183 \frac{q\mu}{kh} \lg \frac{2,25\chi}{r_w^2} + 0,183 \frac{q\mu}{kh} \lg t.
$$

(2)

Let us introduce the notation:

$$
i = 0,183 \frac{q\mu}{kh}; \quad B = 0,183 \frac{q\mu}{kh} \lg \frac{2,25\chi}{r_w^2}.
$$

(3)

Then the expression for $\Delta P(t)$ will be represented as:

$$
\Delta P(t) = B + i \lg t.
$$

(4)

This is a straight line equation. Coefficient $i$ is the slope of the PBU curve in coordinates $\Delta P(t) - \lg t$ (semi-logarithmic coordinates) and is defined as:

$$
i = \tan \alpha = \frac{\Delta P(t_2) - \Delta P(t_1)}{\lg t_2 - \lg t_1}.
$$

(5)

Coefficient $B$ is the segment of the axis $\Delta P(t)$, cut off by the obtained straight line, and is determined at the point $\lg t = 0$.

Equation (1) assumes a linear nature (when plotting the pressure build-up ratio in semi-logarithmic coordinates) of pressure growth after shut-in. However, in real studies of wells, there is practically no pressure build-up curve, which would have a rectilinear shape on the working schedule. The initial section of the pressure build-up in coordinates $\Delta P(t) - \lg t$, as a rule, is deflected towards the abscissa axis (Figure 1).

![Figure 1. Working graph of the pressure build-up curve.](image-url)
The distortion of the pressure build-up ratio at the initial stage of pressure build-up is caused by the continued flow of fluid into the well after its shutdown. The curvature of the initial section of the pressure build-up curve is also affected by the skin-effect.

The graphical representation of the well survey process in semi-logarithmic coordinates allows you to select the final rectilinear section of the pressure build-up test (section AБ). This part of the PBU curve corresponds to the filtration law in the remote part of the formation described by the original equation (1). Therefore, the coefficients and of the equation of the straight line drawn through the last points of the PBU are directly determined from the graph in Figure 1 at the point of intersection of this straight line with the pressure axis and by the tangent of the angle of inclination of the straight line to the abscissa axis.

The reservoir conductivity in accordance with formulas (1) - (4) is determined as follows:

\[
\frac{kh}{\mu} = 0.183 \frac{q}{i}. \tag{6}
\]

Permeability:

\[
k = 0.183 \frac{q\mu}{ih} \quad \text{or} \quad k = \left(\frac{kh}{\mu}\right) \cdot \frac{\mu}{h}. \tag{7}
\]

Piezoconductivity:

\[
\chi = \frac{k}{\mu(m\beta_m + \beta_f)}, \tag{8}
\]

where and - compressibility of the mixture and the formation skeleton, \(P\alpha^{-1}\); m - porosity.

The skin-effect is equal to:

\[
s = 1,151 \left(\frac{P_b(3600) - P_b(0)}{i} - \log\left(\frac{X}{r_w^2}\right) - 3.908\right), \tag{9}
\]

where \(P_b(3600)\) is the bottomhole pressure measured at time \(t = 1h\).

Productivity coefficient:

- actual

\[
\eta_{ac} = \frac{q}{P_r - P_b(0)}; \tag{10}
\]

- potential

\[
\eta_p = \frac{kh/\mu}{0.366 \cdot \log\frac{r}{r_w}}. \tag{11}
\]

3. Results and discussion

As an example, let's calculate the reservoir parameters using the following data from the hydrodynamic study: the well worked continuously for 9 months, after which it was stopped for 8.8 hours and the pressure build-up curve was recorded.

It is known from the well: well flow rate at the bottomhole \(q = 38.4 \, m^3/day\); bottomhole pressure \(P_b = 11.0 \, MPa\); formation thickness \(h = 10 \, m\); porosity \(m = 0.2\); compressibility of the mixture \(\beta_w = 1.1 \cdot 10^{-3} MPa^{-1}\); compressibility of the formation skeleton \(\beta_f = 1.0 \cdot 10^{-4} MPa^{-1}\); oil viscosity \(\mu_o = 1.6\); the radius of the well \(r_w = 0.1 \, m\); radius of an external boundary \(r = 200 \, m\).
Table 1 shows the pressure-time data obtained after processing the pressure diagram.

Table 1. Pressure-time data obtained after processing the pressure diagram.

| №  | $P_1$, MPa | $t$, s | №  | $P_2$, MPa | $t$, s |
|----|-------------|--------|----|-------------|--------|
| 1  | 11,00       | 0      | 12 | 26,12       | 16741  |
| 2  | 11,55       | 955    | 13 | 26,44       | 17330  |
| 3  | 13,02       | 1905   | 14 | 26,48       | 18008  |
| 4  | 14,86       | 2907   | 15 | 26,61       | 19198  |
| 5  | 17,62       | 4820   | 16 | 26,75       | 20077  |
| 6  | 19,93       | 6766   | 17 | 26,82       | 21680  |
| 7  | 21,88       | 8739   | 18 | 26,85       | 23863  |
| 8  | 23,41       | 10454  | 19 | 26,82       | 25604  |
| 9  | 24,67       | 12505  | 20 | 26,85       | 27647  |
| 10 | 25,59       | 14303  | 21 | 26,88       | 29474  |
| 11 | 25,93       | 16152  | 22 | 26,88       | 31623  |

Since the well worked for a long period of time before shutdown and the inflow time is much longer than the pressure build-up time, a working graph with coordinates $\Delta P(t) - \lg t$ was chosen to interpret the pressure diagram.

According to table 1, a work schedule of pressure build-up is built in semi logarithmic coordinates $\Delta P(t) - \lg t$ (Figure 2).

On the straight section of the curve, two points with coordinates ($\Delta P_1$, $\lg t_1$) and ($\Delta P_2$, $\lg t_2$) are arbitrarily selected, for example, points with coordinates ($4,303; 15,75$) and ($4,5; 15,88$), and the value of $i$ is determined:

$$i = \frac{\Delta P_2 - \Delta P_1}{\lg t_2 - \lg t_1} = \frac{15,88 - 15,75}{4,5 - 4,303} = 0,66 \text{ MPa/l.c.}$$

**Figure 2.** Interpretation of build-up pressure curve recorded after prolonged well development.
A segment is measured on the ordinate axis from zero to the point of intersection of this axis with the continuation of the straight section: \( B = 12.9 \text{ MPa} \).

The hydraulic conductivity of the reservoir is equal to:

\[
\frac{kh}{\mu} = 0.183 \cdot \frac{38.4 \text{ m}^3/\text{day}}{0.66 \cdot 10^6} = 0.183 \cdot \frac{38400}{0.66 \cdot 10^6} = 123.23 \cdot 10^{-12} \text{ m}^3/\text{Pa} \cdot \text{s}.
\]

Reservoir permeability is determined by the formula:

\[
k = 123.23 \cdot 10^{-12} \cdot \frac{1.6 \cdot 10^{-3}}{10} = 0.0197 \cdot 10^{-12} \text{ m}^2.
\]

The piezoconductivity is equal to:

\[
\chi = \frac{0.0197 \cdot 10^{-12}}{1.6 \cdot 10^{-3} (0.2 \cdot 1.1 \cdot 10^{-9} + 1 \cdot 10^{-10})} = 0.0385 \frac{\text{m}^2}{\text{s}}.
\]

Skin-effect:

\[
s = 1.151 \left( \frac{26.26 - 11}{0.66} \right) - \lg \left( \frac{0.0384}{0.1} \right) - 3.908 = 21.45.
\]

Productivity coefficient:

- actual

\[
\eta_a = \frac{38.4}{26.88 - 11} = 2.4 \frac{\text{m}^3/\text{day}}{\text{MPa}};
\]

- potential

\[
\eta_p = \frac{123.23 \cdot 10^{-12}}{0.366 \cdot \lg \frac{200}{0.1}} = 8.8 \frac{\text{m}^3/\text{day}}{\text{MPa}}
\]

4. Conclusion

The purpose of this work was to determine the filtration parameters of the formation, such as hydraulic conductivity, permeability, piezoconductivity using the data obtained during the hydrodynamic study of the well. The pressure build-up curve recorded as a result of the study after prolonged well development was rebuilt in semi-logarithmic coordinates and processed by the tangent method.

The use of this technique also makes it possible to assess the state of the bottomhole zone of the well (skin-effect), the obtained value of 21.45 indicates significant contamination of the bottomhole zone. Determination of the actual and potential well productivity coefficient also confirms the contamination of the bottomhole formation zone.

Based on the calculations performed, the potential productivity coefficient turned out to be 3.7 times higher than the actual one. Thus, after carrying out stimulation of the formation, the production rate of the well can be increased almost fourfold.

5. References

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