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Assessment of technological measures effectiveness based on the interpretation of pressure build-up curves using identification equations

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Abstract.

Identification of hydrodynamic studies of wells is important in the control and management of various technological processes of oil production. One of the most used research methods in oilfield practice is taken by taking pressure recovery curves in production wells. Determination of the filtration characteristics of the formation by pressure buildup makes it possible to reasonably select wells under the influence, the method of the impact on the bottomhole zone itself, the necessary optimal operations, as well as to assess the degree of effectiveness of the geological and technological measures being carried out.

Keywords: pressure build-up, production, identification equations, productivity index, unbiased criterion

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1. Introduction

Hydrodynamic methods for assessing the effectiveness of impact on the bottom-hole zone of wells are based on model ideas about the nature of filtration flows and the geological structure of the formation.

Such, for example, are a priori ideas and assumptions about radial filtration, uniformity of the formation in thickness, invariability of the formation pressure at a certain specified distance from the well, etc. In a number of cases, mathematical research approaches and schemes are not adequate to the actual processes occurring during hydrodynamic testing of wells.

Considering this fact, when considering the method for selecting identification equations, one should not accept restrictions in favor of any particular type of mathematical models and simplifying assumptions about the physical properties of reservoirs and the geometric structure of the formation [3].

2. Methodological part

The recovery of pressure in the well is further accepted as a dynamic process, a complete description of which should be presented in the form of a functional relationship

$$\Delta P = \varphi\left(\frac{d\Delta p}{dt}, \frac{d^{\Delta} p}{dt^2}, \ldots, Q_0, Q_1(t)\right) \tag{1}$$

where $\Delta P = p_w(t) - p_w(0)$ is the current drawdown, measured from the initial pressure in the well; $Q_0(t)$ – initial flow rate of the well; Q_1 - inflow into the well after shutdown.

Below, the following are given as partial identification equations that approximately describe the complete equation (1):

$$\Delta P_1 = cQ_0 - bQ_1(t);\ \Delta P_2 = cQ_0 - bQ_1(1) + a_1\frac{d\Delta p}{dt};\ \Delta P_2 = cQ_0 - bQ_1(1) + a_1\frac{d\Delta p}{dt} + a_2\frac{d^2\Delta p}{dt^2} \tag{2}$$

If the pressure in the well has almost been restored and the inflow has stopped, i.e. $Q(t) = \frac{d^i\Delta p}{dt^2} = 0,\quad i = 1,2,\ldots,$ then equations (2) take the form

$$\Delta p = cQ_0 \tag{3}$$

If, when processing the results of pressure build-up observations in the resulting identification equation, the coefficients c and b differ significantly, this is explained by the non-linear nature of the inflow to the well in the corresponding flow rate range. To select an identification equation of optimal complexity, i.e. most adequate to the nature of pressure build-up in a given time interval, as well as to the accuracy and frequency of measurements, we apply the criterion of unbiasedness of the model proposed by Ivakhnenko A.T. [2]. In this case, the entire sample of observations of the current depression $\Delta p(t)$ in a certain time interval $(t_1; t_2)$ is divided into two alternating sequences – training (N_{tr}) and testing (N_{test}). At each observation point, the difference derivatives of the depression are calculated to the required order and the coefficients of the identification equations are determined using the least squares method at the points of the training and testing sequences, respectively

$$N_{tr}: \quad \begin{aligned} \Delta p_1 &= cQ_0 - bQ_1(t) \\ \Delta p_2 &= cQ_0 - bQ_1(t) + a_1\frac{d\Delta p}{dt} \end{aligned}$$

$$N_{test}: \quad \begin{aligned} \Delta p^*_1 &= c^*Q_0 - b^*Q_1(t) \\ \Delta p^*_2 &= c^*Q_0 - b^*Q_1(t) + a^*_1\frac{d\Delta p}{dt} \end{aligned}$$

The criterion of unbiasedness of the k^{th} model is calculated:

$$\delta^k_{unbias} = \frac{1}{N}\sum_{i=1}^{N}\left[\Delta p_k(t_i) - \Delta p^*_k(t_i)\right] \tag{4}$$

$$N = N_{tr} + N_{test}$$

The summation in (4) is carried out over all observation points, including both the training and testing sequences. As the identification equations become more complex, the unbiased criterion δ^k_{unbias} first decreases and then begins to increase. The optimal complexity model is the one for which the minimum value corresponds δ^k_{unbias}. If, in the process of increasing the complexity of identification models, a stable minimum criterion δ^k_{unbias} is not obtained, the initial sample of the training and testing sequences should be changed [1,4].

3. Results and discussion

The pressure buildup of a well was processed according to the procedure given below. Current depression was measured for 750 minutes at intervals $\Delta t = 10$ min. The well production before shutdown was $Q_0 = 20\ m^3 / day$. Results are shown in Table 1.

The pressure buildup was processed under the assumption that there was no inflow into the well after shutdown, i.e. $Q_1(t) = 0$.

The points in the training sequence corresponded to:

N_{tr} : *t_1=270 min., t_3=310 min., t_5=330 min., t_7=370 min., ...*

The points in the testing sequence corresponded to:

N_{test} *: t_2=290 min., t_4=320 min., t_6=350 min., t_8=390 min., ...*

Difference derivatives at the corresponding points are calculated using the formulas:

$$\frac{\Delta p}{\Delta t} = \frac{\Delta p(t_0+\Delta t) - \Delta p(t_0)}{\Delta(t)};\quad \frac{d^2\Delta p}{dt^2}(t=t_0) = \frac{\Delta p(t_0+\Delta t) - 2\Delta p(t_0) + \Delta p(t_0-\Delta t)}{\Delta t^2};$$

$$\frac{d^3\Delta p}{dt^3}(t=t_0) = \frac{\Delta p(t_0+\Delta t) - 3\Delta p(t_0) + 3\Delta p(t_0-\Delta t) - \Delta p(t_0-2\Delta t)}{\Delta t^3} \tag{5}$$

where Δt is the time interval between measurements of the current depression $\Delta p(t)$.

For example:

$$\frac{\Delta p}{\Delta t} = \frac{14,78 - 14,48}{10} = 0,3 \cdot 10^{-4}\ MPa/\sec$$

$$\frac{d^2\Delta p}{dt^2} = \frac{14,78 - 2\cdot 14,48 + 14,14}{\Delta t^2} = -0,04 \cdot 10^{-8}\ MPa/\sec^2$$

$$\frac{d^3\Delta p}{dt^3} = -0,04 \cdot 10^{-12}\ MPa/\sec^3$$

Since the quantities $\frac{d^3\Delta p}{dt^3}$ are of the order of magnitude $\sim 10^{-12}$, intermediate calculations when determining the coefficients of the identification equations should be carried out up to a value of the order of $\sim 10^{-12}$.

To determine the k^{th} identification model using the least squares method, based on the points of the training and testing sequence, it is necessary to solve the following system of linear algebraic equations (for ease, the notation $a_0 = cQ_0$ is introduced). Based on the points of the training sequence

$$\sum_{r=0}^{k} a_r A_{rs} = B_s, \quad s = 0,1,2,...,k \tag{6}$$

where the coefficients of matrix *A* and vector *B* are defined as follows

$$A_{00}=N_{tr},\ A_{0s}=\sum_{i-1}^{N_{tr}}\frac{d^s\Delta p}{dt^s}(t_i),\ s\geq 1;\ A_{rs}=\sum_{i=1}^{N_{tr}}\frac{d^r\Delta p(t_i)}{dt^r}\frac{d^s\Delta p(t_i)}{dt^s},\ r\geq 1,\ s\geq 1$$

$$B_0=\sum_{i=1}^{N_{tr}}\Delta p(t_i);\ B_s=\sum_{i=1}^{N_{tr}}\Delta p(t_i)\frac{d^s\Delta p(t_i)}{dt^s},\ s\geq 1 \qquad (7)$$

In (7) the sums are carried out only over the points of the training sequence.
By points of the test sequence:

$$\sum_{r=0}^{k}a_r^*A_{rs}^*=B_s^*,\ s=0,1,2,...,k;\ A_{00}^*=N_{test},\ A_{00}^*=\sum_{i=2}^{N_{test}}\frac{d^s\Delta p(t_i)}{dt^s};\ s\geq 1 \qquad (8)$$

$$A_{rs}^*=\sum_{i=2}^{N_{test}}\frac{d^r\Delta p(t_i)}{dt^r}\frac{d^s\Delta p(t_i)}{dt^s},\ r\geq 1,\ s\geq 1;\ B_{i=2}^*=\sum_{i=1}^{N_{test}}\Delta p(t_i);\ B_s=\sum_{i=2}^{N_{test}}\Delta p(t_i)\frac{d^s\Delta p(t_i)}{dt^s},\ s\geq 1$$

Thus, the minimum value of the unbiased coefficient was obtained for the model

$$\Delta p=a_0+a_1\frac{d\Delta p}{dt}=cQ_0+a_1^*\frac{d\Delta p}{dt}$$

For the average value of the productivity coefficient we obtain:

$$K_{avg}=\frac{1}{2}\left(\frac{1}{c}+\frac{1}{c^*}\right)=\frac{1}{2}\left(\frac{Q_0}{a_0}+\frac{Q_0}{a_0^*}\right)=9,87\frac{m^3}{day\cdot MPa}$$

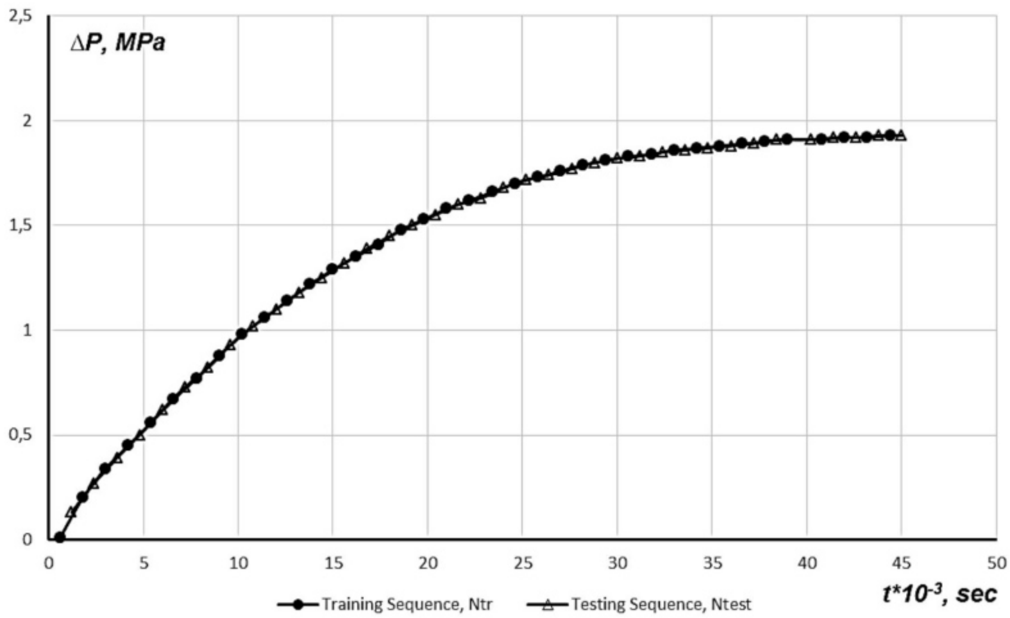

Fig. 1. Dependence curve ΔP=f(t)(Pressure Build-up Curve – Training and Testing Sequences)

Table 1

Results of PBC (Pressure Build-up Curve) processing

Training sequence, N_{tr}		***Testing sequence, N_{test}***	
$t^{3-}10$-, second	***ΔP*, MPa**	***$t^{3-}10$-, second***	***ΔP*, MPa**
0,6	0,01	1,2	0,13
1,8	0,2	2,4	0,27
3	0,34	3,6	0,39
4,2	0,45	4,8	0,5
5,4	0,56	6	0,62
6,6	0,67	7,2	0,73
7,8	0,77	8,4	0,82
9	0,88	9,6	0,93
10,2	0,98	10,8	1,02
11,4	1,06	12	1,1
12,6	1,14	13,2	1,18
13,8	1,22	14,4	1,25
15	1,29	15,6	1,32
16,2	1,35	16,8	1,39
17,4	1,41	18	1,45
18,6	1,48	19,2	1,5
19,8	1,53	20,4	1,55
21	1,58	21,6	1,6
22,2	1,62	22,8	1,63
23,4	1,66	24	1,68
24,6	1,7	25,2	1,72
25,8	1,73	26,4	1,74
27	1,76	27,6	1,77
28,2	1,79	28,8	1,8
29,4	1,81	30	1,82
30,6	1,83	31,2	1,83
31,8	1,84	32,4	1,85
33	1,86	33,6	1,86
34,2	1,87	34,8	1,87
35,4	1,88	36	1,88
36,6	1,89	37,2	1,89
37,8	1,9	38,4	1,91
39	1,91	40,2	1,91
40,8	1,91	41,4	1,92
42	1,92	42,6	1,92
43,2	1,92	43,8	1,93
44,4	1,93	45	1,93

The calculated value K_{avg} of the productivity coefficient coincides with the value of the productivity coefficient determined from the indicator diagram. The relative error does not exceed *3%*. It should be noted that the minimum of the unbiased criterion may correspond to different models depending on the selected interval for processing the pressure build-up curve. Regarding models, it is necessary to do the following: in the solution of the corresponding differential equation, terms of the $e^{e^{\omega t}}$, $\omega \succ 0$ form may be present. This is explained by the fact that the function of complete description of an object (1) in the general case depends on derivative depressions of a higher order than those considered in the proposed model. Therefore, when physically interpreting the coefficient $a_0 = cQ_0$, one should proceed from the conditions of smallness of the derivatives of depressions with respect to time, and not from solving the corresponding differential equation at $t \to \infty$.

4. Conclusions

Therefore, the calculation sequence when determining the productivity coefficient of a well using pressure build-up should be as follows:

- ✓ The points of the training and testing sequence are selected.
- ✓ Derivatives are calculated to the required order for the selected control points.
- ✓ From the system of linear algebraic equations (6-8), the coefficients a_i and a^*_i i.e. identification equations of the object are determined according to the training and testing sequences, respectively.
- ✓ For each model, the δ^k_{unbias} unbiased criterion is calculated using (4).
- ✓ Based on the stable minimum criterion δ^k_{unbias}, the most optimal model is selected.
- ✓ The average value of the productivity coefficient is determined by the formula $K_{avg} = \frac{Q_0}{2}\left(\frac{1}{a_0} + \frac{1}{a^*_0}\right)$

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research.

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