THE WELL NEIGHBOURHOOD TESTING BY HIGH FREQUENCY FILTRATIONAL WAVES METHOD

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The vertical wells investigations are shown by the harmonic filtrational pressure waves method for shot time periods with minutes and tens minutes. The conclusion is made about the actual by putting the depth and mouth devices to well porous neighbourhoodconditions. The special features of the interpretation the similar experimental results is considered.

The well neighborhood investigation results are topical as the point of view the treatment of well decision made, estimation of this treatment efficiency and correct building of the currently working deposit model in situation the agreement between computed and real bottom-hole pressure data is important also. The values of filtration well neighbourhood stratum parameters may significantly differ from the average values for the porous reservoirs. The opportunities of hydrodynamical sounding method using of a well neighbourhood will be considered by the example of vertical well boredin porous single-layer systems.

The method of periodic hydrodynamical interwell intervals sounding, known as the filtration (harmonious) pressure waves (FPW) method, has been developed for a long time ago [1,2]. The nonfrequent abundance this method in practice has been a problem a technical features of carrying out the hydrodynamical experiments, experimental result interpretation for real reservoir conditions problems [3] and long time necessary for carrying out the investigations. A special high-frequency case (from hydrodynamical point of view) of this method for investigation the separate well vicinity with period , as a rule, 10^2-10^4 seconds (or frequencies $\omega \sim 10^{-1}$–10^{-3} rad/sec, correspondingly) is called self-sounding one of well neighborhood. Its realization does not demand a long time of well stoppage and allows to construct a picture of hydroconductivity changes with distance from the well form units to ten meters. There is no necessity to take into account the phenomenon of flow fluid in well after shutdown (afterflow phenomenon) , inherent in a method of pressure restoration curve, and introducing the errors into interpretation results. Radius of hydrodynamical sounding R is proportional to $\sim\sqrt{\chi T}$, where χ - piezoconductivity. This radius is set by the experimenter by prescribing the corresponding period T of harmonious output (rate production) oscillations. It is obvious the concept of sounding radius has conditional character and there is the certain arbitrariness in a choice of his value. In this context the question is about such values of *R*, that the amplitude of pressure in distance from a well falls more than 3 order times. By this mean at $\chi \sim 10^{-1}$ *м²/с* and the periods till 10^3 seconds the sounding radius is equal to 15 meters. In doing so, the time of carrying out of a full investigation number of a well neighborhood with 10-15 various periods will make several hours.

Analytical expressions for interpretation the results of experimental researches with use of a considered method have been received and studied by S.N.Buzinov and I.D.Umrikhin [1] and Y.M.Molokovich [2]. In the investigations by a self-sounding method with fixed period *T* of harmonious outputt oscillations (correspondingly, fixed frequency value ω), according to measurements data the graphs of time-varying output and pressure on bottom-hole are $q(t)=q_0\sin(\omega t)$ and $P_c(t)=P_0\sin(\omega t-\Delta)$. There will be some phase shift Δ between the established harmonious output oscillations and pressure. With a knowledge of this shift, output oscillations amplitudes and pressure for each concrete frequency (period) it is possible to determine the filtrational parameters of a reservoir such as hydroconductivity ε и and complex χ/r_c^2.

At the condition

$$z_c=r_c\sqrt{\frac{\omega}{\chi}}<<1 \qquad (1)$$

these parameters may be calculated by relatively simple approximate formulas:

$$\varepsilon=\frac{q_0}{8\mathrm{P}_0\sin\Delta} \qquad (2)$$

$$\frac{\chi}{r_c^2}=\frac{\gamma^2}{4}\omega\cdot\exp\frac{\pi}{2\mathrm{tg}\Delta}\ . \qquad (3)$$

Here q_0 - amplitude of output oscillation, P_0 - amplitude of pressure oscillation, γ = 1.781 - Euler's constant, r_c - the reduced well radius. The phase shift Δ is connected to dimensionless parameter z_c with relation

$$\Delta=arctg\frac{\pi}{4\ln\frac{2}{\gamma z_c}}\ . \qquad (4)$$

For a higher values of parameter z_c (for example, r_c ~ 10^{-1} m, χ~10^{-2} m^2/sec, $\omega = 2\pi/T \sim 10^{-1}$ rad/sec, $z_c \sim 0.3$) are used the exact, but seldom used formulas:

$$\varepsilon = \frac{q_0}{2\pi P_0 z_c} \sqrt{\frac{\ker_0^2 z_c + kei_0^2 z_c}{\ker_1^2 z_c + kei_1^2 z_c}} \,, \tag{5}$$

$$\Delta = \frac{\pi}{4} - arctg\left(\frac{\ker_1 z_c \cdot \ker_0 z_c + \mathrm{kei}_1 z_c \cdot \mathrm{kei}_0 z_c}{\ker_0 z_c \cdot \mathrm{kei}_1 z_c - \mathrm{kei}_0 z_c \cdot \ker_1 z_c} \right). \tag{6}$$

Here *ker* and *kei* - Calvin's functions. In case of the complex (but periodic) output in linear systems it is possible to decompose a signal in the Fourier series and to consider the separate harmonics of these series. Cases of environments with complex reology are considered in [2].

It would seems that there are not a problems with interpretation, as it is simple to find the roots of the equation (6), using modern mathematical packages such as *Maple* or *Mathematica.*

However a number of the natural experiments which have been made on the wells of the Central – Aznakaevsk's area Romashkino deposit (terrigen porous reservoir D_I; system – single-layer; a water in development wells production – 90-99 %; bottom-hole - 1800 meters), has furnished the results, which were not fit to the preceding circuit as resulted to abnormal extremely great values of phases shift Δ*,* even more than unit under the sounding periods less than 1000 seconds. It should be mentioned that the formula (6) restricts a limiting value Δ to *π/4~0.78*. For development wells shift of phases was essentially less, than for injection well, maintained during experiments in a mode "injection – outage" and researches of the same injection well in a mode "flow out – outage" are resulted in more realistic values Δ .

It was found under interpretation the investigation results by a self-sounding method is necessary to take into account a number of the peculiarities connected to conditions of carrying out the experiments. This paper is devoted to investigations of such peculiarities.

First of all, we shall find out a condition of applicability of approximation $z_c \ll 1$. Fig. 1 gives the dependences $\Delta_p\ (z_c)$ and $\Delta_t\ (z_c)$ for approximation (4) and exact decision (6), accordingly, are shown. At the same figure according to numerical integration, value of phase shift Δ_{ch} (z_c) - coincident with exact the decision Δ_t (z_c) is indicated.

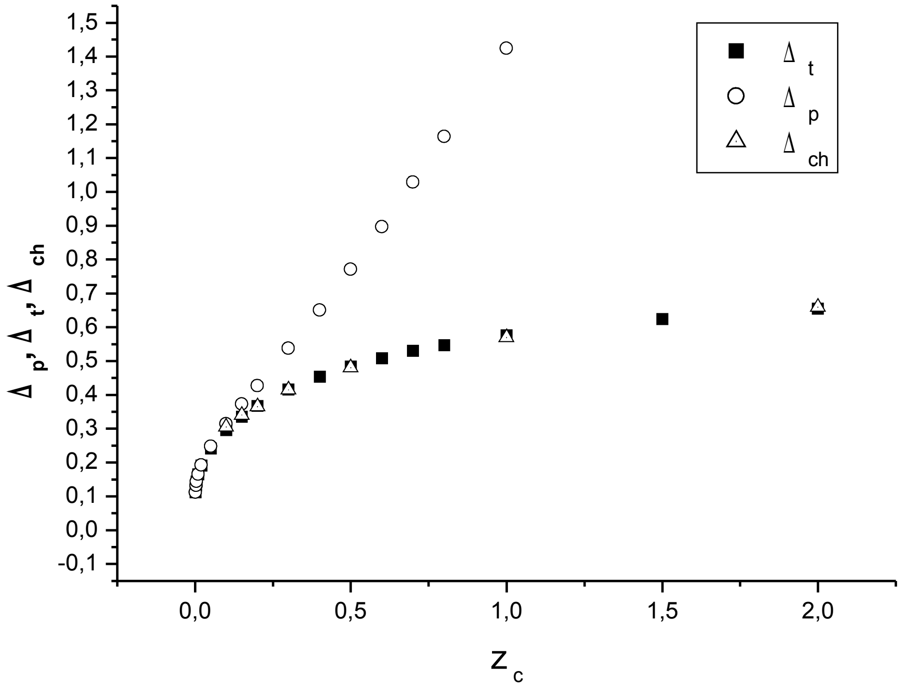

Figure 1. The phase shift dependences on values of parameter z_c for the approximate, exact analytical decisions and numerical calculation

We can conclude that using of formulas (2) - (3) is satisfactory at values $z_c < 0.1 - 0.15$. At great values z_c follows, obviously, to use formula (5) and (6), that corresponds to phases shifts $\Delta > 0.20$. It should be noted the dependence z_c (Δ) in an interval $0.2 < \Delta < 0.6$ with rather good approximation (R^2=0.9993) can be described by the polynominal formula: $z_c = 75.423\Delta^4 - 89.166\Delta^3 + 40.783\Delta^2 - 7.3052\Delta + 0.437$ that covers the majority of situations with experiments on high-frequency self-sounding. However to explain the results of some natural experiments simple recalculation with formulas (5-6) using is appeared insufficiently.

Passing to the analysis of carrying out the self-sounding experiments conditions we should noted that at set to work a well with the big pressure difference at the moment of time $t = 0$, in a tubes of a well the hydrodynamic waves extending in a well with acoustic speeds and pressure differences are observed up to units of atmospheres.

The attenuation of tube pressure fluctuations occurs through time *t ~100* seconds that is comparable to the periods of set fluctuations. For exception of this elastic - dynamic effect, one of which negative consequences are parasitic gallop of values of measured parameters at use of discrete times of gaugings. In [4] was used special the latch - tap, allowing to set quasigarmonic output oscillations. It has allowed to overcome the instability of the pressure signals connected with distribution of "shock" hydrodynamic waves.

The following question: to what degree the indications of mouth devices correspond to values of amplitudes and pressure used in calculations and how they are correlated in time? Usually the measuring equipment (a manometer and flowmeter "turboquant" tipe) are established on a well mouth, with flowmeter - on a mouth at an entrance of pump-compressor tubes, and a manometer - in casing tubes. The variant of results of similar research is shown in fig. 2 for injection well 4379a number as the example of which the subsequent calculations will be resulted.

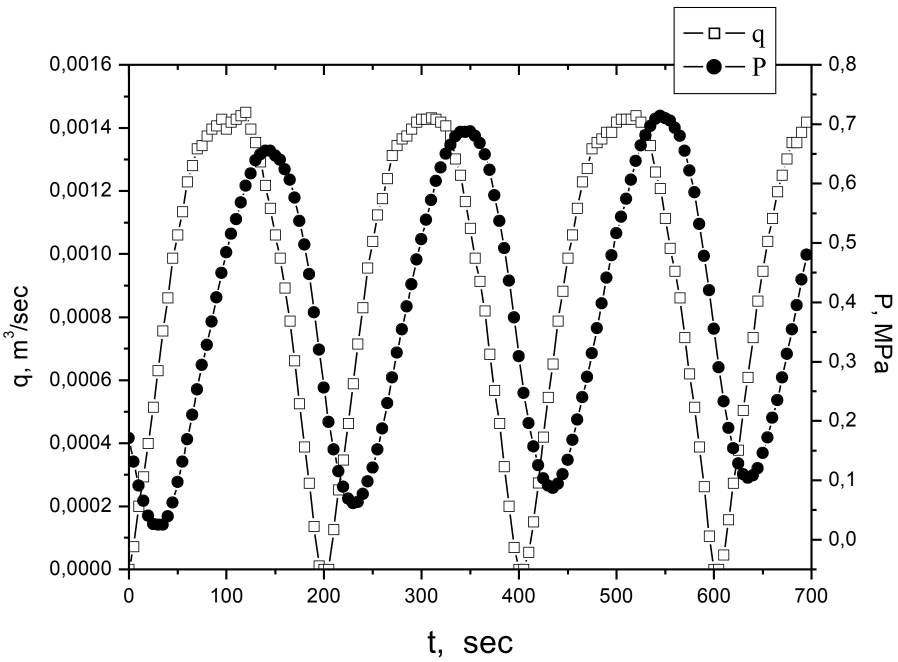

Figure 2. Dynamics of the output q registered by mouth flowmeter and pressure P registered by a manometer on casing

For testing purposes were used the manometers in a mouth of PCT and a deep manometer on bottom-hole, in addition to a manometer on casing also. The persuaded researches have shown, that values of pressure measured by mouth manometers in casing and in PCT differ with a depth manometer, that is shown in fig. 3. Experiments data indicate some nonequivalence the forms measured signals for even and odd half-cycles of oscillations both under and on duration.

Thus, experiments have shown both presence of time lags in indications of devices, and distortion of the form of signals on pressure. Outputs differ measured on a mouth and on bottom-hole also. There is a question: what values of the output and pressure should be taken for the subsequent interpretation and calculations of reservoir filtration parameters and with what phases?

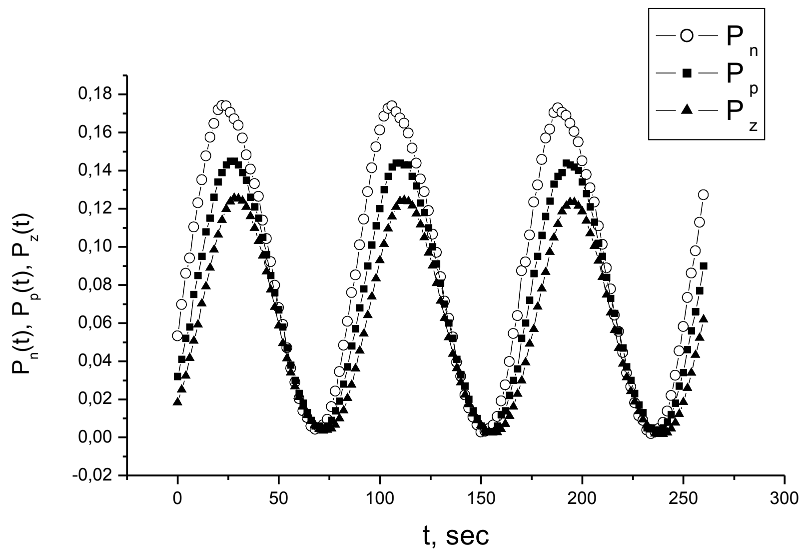

Figure 3. Indications of three manometers established on a mouth in PCT (P_H), on bottom-hole near to a reservoir (P_p) and on casing tubes (P_z)

For correct calculation of phase relations it is necessary to take into consideration the following mechanisms:

1. Existence of the time delay connected to distribution of a signal in a tube of a well. Certainly, at the periods of output oscillations at units of hours, it is insignificant, however for period $T = 50$ seconds, 1 second is already 0.12 radian of the correction to a phases difference.

2. Drop of pressure brought on by friction of a liquid together of the tube walls. It leads to distortion of the form of a signal, with corresponding additional phase shift, and changed his pressure amplitudes. This appear on a calculation of hydroconductivity (the real reservoir flowrate will be less on amplitude, than mouth flowrate, and the amplitude of pressure will be more, than measured on casing).

3. There is the "attached" volume of a liquid into a well which does not pass really in a reservoir, but is registered by mouth devices and is present in a well, being connected with processes of compression - releases of a liquid in a tube of a well in a mode the «injection – outage». This attached volume can be significant from the point of view of phase relation. In our experiments $V_0 \beta_* \Delta p = \Delta V \sim 1-5 \cdot 10^{-3} м^3/c$ (here β_* - compressibility of a liquid in volume V_0 of a well at pressure difference ΔP), that at flowrate $q_0 \sim 10^{-3} m^3/\sec$ means duration of process of the compression, equivalent to units of seconds.

Thus, phase delays in 10 - 20 seconds connected with way of registration of real signals on the periods of investigation of 100 - 200 seconds are equivalent to additional shifts of phases ~ 0.5-1.0. In our opinion this facts should be taken into account to answer a next question. What do the "manometer" and "flowmeter" show? In other words, it is necessary to result the indications of mouth devices to the reservoir conditions.

In view of recalculation the phase shifts for each separate period according to indications of three manometers we have plotted the graph with the dependence Δ from periods *T* in addition to the graph have constructed in according to direct devices data (flowrate in a mouth and a manometer in casing). In figure 4 experimentally received shifts of phases are shown. Black squares indicates dependence Δ *(T)* designed from the data mouth devices without correction (formal calculation), and hollow circles - the calculated values Δ in view of a delay of signals at distribution on a tube of well and corrections on friction and compressibility (it is accepted equal $5.5 \cdot 10^{-10}$ Pa^{-1}) of a liquid volume in a well are shown. We see, that the phase shifts became more realistic (less than $\pi/4$). In figure 4 the data of researches of a well 4379a in different days and with the different periods are indicate. Nevertheless, the curve Δ*(T)* has rather smooth character that speaks about stability of received experimental data.

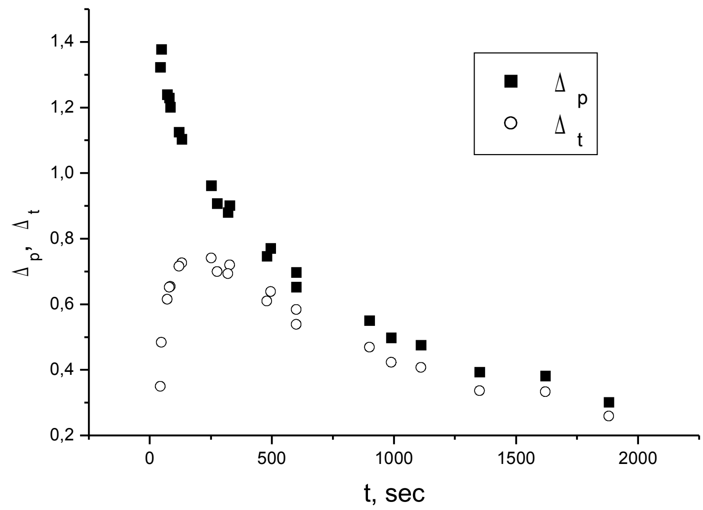

Figure 4. Frequency dependence the phase shifts for a case of formal calculation and in view of the correction connected to reduction of pressure and flowrate to reservoir conditions

It is possible now to consider the «dynamical» hydroconductivity $\varepsilon(r)$. More precisely the tendency of this dynamics as dependence $\varepsilon(T)$ and dynamics of parameter χ / r_c^2 show in fig. 5. The data received on index points of primary segments (with the periods of sounding till 100 seconds) certainly are less reliable. Probably high value hydroconductivity near to the well is connected with fractured collector. Then the zone with lowered hydroconductivity values in the periods $10^2 < T < 10^3$ sec and monotonous growth of values hydroconductivity is observed in process of growth of the period of hydrosounding. It take be noted that in a well 4379a it was earlier made polymeric systems injection and this procedure have probably worsened permeability in distances about 5-20 meters near to a well. We observe a corresponding picture the parameter χ / r_c^2 also which is less reliable at similar sorts researches than hydroconductivity.

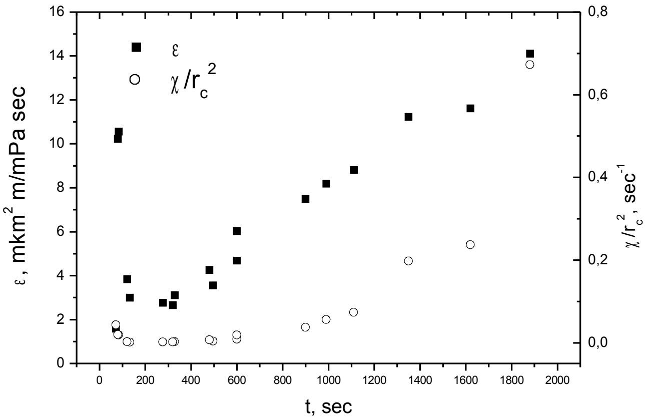

Figure 5. Calculated value hydroconductivity and parameter $\chi\ /\ r_c^2$
in view of the made correlations depending on the period of the flowrate oscillations

CONCLUSIONS

The hydrodynamical self-sounding method may be effectively used to investigate the well neighborhood reservoir under condition of correct calculation the amplitudes and phases the output and pressure related to system "reservoir – well".

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