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DEVELOPMENT OF MATHEMATICAL MODEL AND ALGORITHM FOR CALCULATING PARAMETERS OF HYDRODYNAMIC INTENSIFICATION OF GAS RELEASE FROM BOREHOLES

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Abstract. The work validates a mathematical model for calculating parameters of the impulse impact on the bottomhole zone of a well through a liquid with different physicochemical properties to increase gas extraction from the rock mass. Existing calculation methods describing the hydrodynamics of the pulse propagation process in a liquid are described and analyzed. A mathematical model is proposed for calculating hydrodynamic processes occurring in a well during impulse impact, which includes quasi-linear hyperbolic-type gas dynamics equations with initial and boundary conditions. A distinctive feature of the model is the consideration of the oscillation source pulsations. A block diagram of the algorithm for calculating the hydrodynamic pulse parameters is presented. The linear flow of the liquid in the well between its bottomhole and the impulse source is considered. It was established that the key parameters significantly influencing the hydrodynamic processes in the well are its length, the pressure in the cavity of the oscillation source and the coordinate of its boundary, as well as the pressure at the bottom of the well. The dynamics of pressure profile distribution along the length of the well at different time points under varying initial parameters of the impulse impact was established. The dependences of the pressure in the oscillation source and at the bottomhole and the change in the coordinate of the boundary of the oscillation source cavity over time under different impulse impact modes were calculated and analyzed. The influence of the duration of the oscillation source impulse on the process parameters at different distances to the bottomhole was studied. It was established that the state of the bottomhole zone of the well for the purpose of gas extraction intensification can be effectively controlled both by adjusting the impulse impact parameters and by using various physicochemical compositions as the working liquid. Varying the liquid composition during the impulse impact leads to a change in the amplitude and time of impulse arrival at the bottomhole of the well.

The results of the research can be used to calculate hydrodynamic processes during impulse treatment of gas extraction wells in order to intensify gas release by changing impulse impact parameters and by using different physicochemical compositions as the working liquid.

Keywords: gas extraction well, gas release intensification, impulse impact, hydrodynamic processes.

1. Introduction

Development of new methods for intensifying mineral extraction is a pressing scientific challenge. To select and substantiate such methods, theoretical study is required to establish the main regularities of the underlying processes. When extracting gas from rock mass, it becomes necessary to relieve stress from the rocks surrounding the well [1, 2]. Currently, a number of methods are used for this purpose, ranging from torpedoing the rock mass to its physicochemical treatment. However, none of these methods fully meets modern production requirements. Some of them are accompanied by high risks, while others do not guarantee sufficient efficiency [3–5]. Due to the presence of aquifers, wells are often filled with water. Therefore, the use of hydroimpulse impact appears to be a promising approach for this purpose. To determine rational parameters of such an impact, it is necessary to evaluate the pressure at the bottomhole under different operating modes of the oscillation source and with different composition of the liquid filling the well.

The effectiveness of the impulse impact on the well walls during gas extraction is primarily determined by the pressures that are generated within the liquid-filled volume, that is, they are ultimately governed by hydrodynamic processes in the well [6–8]. Experimental studies of these pressures face challenges such as the difficulty of

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registering data at great depths and converting sensor readings into power parameters. These studies are labor-intensive and do not always guarantee obtaining reliable results. All of the above necessitates theoretical research of the hydrodynamic processes that accompany the impulse impact in the well.

In hydrodynamic calculations, the most common models include: self-similar approximation, compressed liquid model, acoustic model, the Kirkwood-Bethe model, and others [9–13]. The use of self-similar solutions is limited by the time interval, since the assumptions about the constancy of the elastic wave propagation velocity and the instantaneousness of the impulse impact on the flow towards the front of the compression wave are only valid for short duration of the impact. The compressed liquid model can give satisfactory results only in the region of immediate vicinity to the impulse source. The acoustic model cannot describe such important hydrodynamic processes as the formation of a compression wave and its interaction with waves generated by the impulse source. The equations that describe the motion of the liquid in the Kirkwood-Bethe assumption do not follow from the hydrodynamics equation and are instead a successful experimental assumption, therefore the use of this approach is always questionable, and its results require additional verification.

Considering the drawbacks of these approximations, determining liquid motion under impulse impact requires solving the gas dynamics equations that strictly describe the compressibility of the medium. High pressures, the presence of compression waves, reflection of waves from boundary surfaces - all these factors necessitate the use of numerical methods to calculate the created flows. The results of the initial studies in this area are presented in the works [14, 15]. A similar approach to determining the hydrodynamic parameters of the impulse impact is further developed in this work.

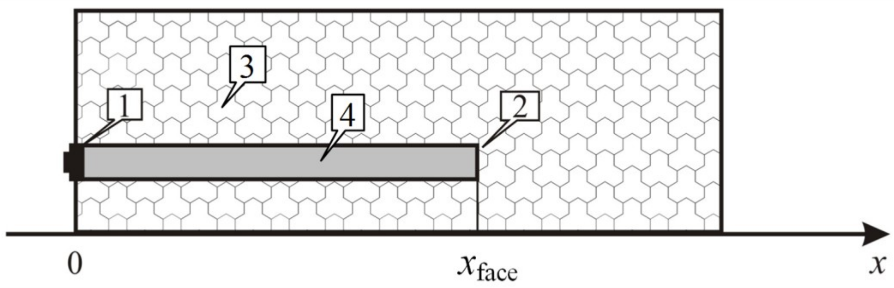
The purpose of this work is to validate a mathematical model for calculating the parameters of the impulse impact on the bottomhole zone of the well through a liquid with different physicochemical properties in order to increase gas release.

The task of this research is to develop an algorithm and to calculate the parameters of the impulse propagation process in a well filled with liquids with different physicochemical properties in order to intensify gas extraction.

2. Methods

The problem statement. Let us consider a linear model of impulse propagation in the form of pulsations between the oscillation source 1 and the bottomhole 2, which is located in the rock mass 3 and filled with liquid 4 (Fig. 1). The oscillation source is a cavity filled with gas, into which energy is supplied according to a predetermined law in the form of a decaying sinusoid. According to this law, the cavity oscillates, generating compression and extension waves that propagate in the liquid.

Assumptions. We assume that between the impulse source and the bottomhole the cross-section of the well is constant. Then, taking into account that the pulse generation duration t_1 is at least 0.1 ms and $d/a_0 t_1 \prec 10$ and $d/L \prec 10$ (where d, L is diameter and length of the well, a_0 is speed of sound in the liquid), the channel approximation can be applied to hydrodynamic calculations [15].



1 – impulse oscillation source; 2 – bottomhole; 3 – rock mass; 4 – liquid;
x_{face} – distance from the oscillation source to the bottomhole

Figure 1 – Scheme of hydroimpulse treatment of a gas extraction well

We further assume that the time dependence of the generated impulses is specified in advance, and at the initial moment of time the liquid is not yet disturbed. The model does not take into account changes in thermodynamic parameters in the oscillation source, energy losses due to thermal conductivity of the liquid and changes in the stiffness of the well walls.

The pressure in the liquid during impulse impact does not exceed 100 MPa and, therefore, the equation of the dependence of pressure P_1 on density ρ_1 in the Theta form can be taken as the equation of state for it [16]

$$P_1 = B(\rho_1/\rho_0)^n - B, \tag{1}$$

where the initial liquid density is $\rho_0=10^3$ kg/m^3, and the constants B and n are calculated based on the composition of the liquid (for technical water B=304.5 MPa, n=7.15).

Then the one-dimensional unsteady flow of an ideal liquid - in the sense that its viscosity and thermal conductivity are neglected – is described by a dimensionless system of equations [17]:

$$\frac{\partial}{\partial t}\rho + \frac{\partial}{\partial x}\rho u = 0,$$

$$\frac{\partial}{\partial t}\rho u + \frac{\partial}{\partial x}\left(P + \rho u^2\right) = 0, \tag{2}$$

$$P = \rho^n - 1.$$

Here, the following values are taken as a scaling parameters: density $\rho = \rho_0$, pressure $P = B$, velocity $u = a_0$, time $t = t_0$ (characteristic time equal to the duration of the impulse impact), length $x = a_0 t_0$.

Initial conditions:

$$\rho(x_0, 0) = (P_0 + 1)^{1/n}, \quad u(x_0, 0) = 0, \quad x \in (x_{m0}, L)$$

$$u(x_{m0}, 0) = 0, \quad \rho(x_{m0}, 0) = (P_{m0} + 1)^{1/n}, \tag{3}$$

where x_{m0} is the coordinate of the boundary of the oscillation source cavity at the initial moment, P_0 is the initial pressure in the well, L is the length of the well (the distance from the source to the bottomhole), $P_{m0} = P_m(0)$ is the initial pressure generated by the impulse source.

The condition on the contact surface "boundary of the oscillation source cavity - liquid" is written as follows:

$$\frac{\partial \rho_m}{\partial t} = \frac{(\gamma - 1) \cdot N / x_m - \gamma(\rho_m^n - 1) \cdot u_m}{n x_m \rho_m^{n-1}}, \tag{4}$$

where $\gamma = 1.26$ is effective adiabatic index, $N = N(t)$ is specific power of the oscillation source per unit of well cross-section area (scale is $N = B a_0 t_0$, $\rho_m = \rho(x_m, t)$, $u_m = u(x_m, t)$).

All well walls are assumed to be absolutely rigid. Therefore, the condition $u(L, t) = 0$ may be satisfied at the bottomhole.

The dependence *N(t)* was given as a piecewise linear function, with zeros at time points $t_k = t \cdot k$ and local maxima at time points $t_{km} = t \cdot (k - 0.5)$, where $k = 2, 3, \ldots, s$; where *s* is the number of analyzed pressure impulses.

For solving quasilinear hyperbolic equations, which include the gas dynamics equations, the method of S.K. Godunov [18] has gained widespread use. Successfully combining the advantages of the method of characteristics and end-to-end calculation schemes, it suggests, in particular, the solution of a number of complex problems on the calculations of unsteady water flows [19, 20].

By integrating the system of equations (2) over the region in the (*x, t*) plane bounded by the closed curve *G*, and passing to contour integrals along the curve *G* using Green's formula, we obtain:

$$\oint_G (\rho\, dx - \rho u dt) = 0$$

$$\oint_G \left(\rho\, dx - \left(\rho u^2 + (\rho^{n-1} - 1)/n\right) dt\right) = 0 \tag{5}$$

The solution of this system was carried out according to the well-known method [17, 21] using a modified algorithmic scheme (Fig. 2), which differs by incorporating the specific power of the oscillation source per unit of cross-sectional area of the well and by performing a layer-by-layer calculation of the density and velocity of the liquid during passing impulses of different durations.

	Entering of initial data	
geometric	technological	mode
the well length and diameter	initial density of the liquid	duration of impulses and frequency of their passage

↓

	construction of the calculation domain grid at the initial time point $t=t_0$	
assignment of coordinates of grid nodes x_i	determination of layer thickness $x_{i+1}-x_i$	assignment of initial values $\rho_{i+1/2}$ and $u_{i+1/2}$

↓

	calculation of parameter values at the time point $t=t+\tau$	
calculation of the velocity of the grid nodes moving $W_i=\left(x^i-x_i\right)/\tau$	calculation of density and velocity at the internal boundaries at $R_i=t$, $U_i=t$	calculation of density and velocity at the cell boundary $\rho^{i+1/2}$ and $u^{i+1/2}$

↓

time point $t = t_0$ construction of the calculation domain in the form of a grid with nodes at points with coordinates x_i; calculation of the density at the left boundary of the calculation domain (the boundary of the oscillation source), calculation of this boundary based on the density; the velocity of the grid internal nodes is determined equal to the velocity of the left boundary of the calculation domain using the calculations of the discontinuity decays between the parameters in the cells; calculation of the velocity of the right boundary movement within the calculation domain (compression wave) and the parameters on it, followed with selection of the time step
time point $t=t+\tau$ determination of the grid node coordinates and calculation of the parameters in the cells; checking the width of the last cell and increasing the number of cells, if necessary; obtaining the distribution of the flow parameters
recalculations for each layer calculation of the values of the velocity $u_{i+1/2}$ and density $\rho_{i+1/2}$ inside each layer; calculation of the values at the boundaries of the calculation domain and the velocity of the boundaries themselves; selection of the acceptable time step τ; calculation of the grid boundaries coordinates at the point time $t=t_0+\tau$: $x^{\prime}=x_i+W_i\tau$
time point $t=t_i+\tau$ calculation of the layer thickness $x_{i+1}-x_i$; calculation of values of the velocity $u^{i+1/2}$ and density $\rho^{i+1/2}$ inside each layer; calculation of the velocity of the i--th node $W_i=\left(x^i-x_i\right)/\tau$ during the time step; comparison of parameters in neighboring grid layers; calculation of the parameters of the discontinuity decay at the i-th boundary R_i, U_i; determination of the velocity direction in the discontinuity decay region
selection of flow configuration by the pressure-to-velocity ratio in neighboring cells – if the medium velocity in the analyzed node is directed into the cell to be calculated, then the density corresponds to the state of decay behind the contact surface in the direction of its movement
the time point of the compression wave arrival at the bottomhole calculation of the flow along the entire domain between the boundary of the oscillation source and the wall by the "through-flow calculation" method without isolating possible discontinuities; the values of

R_i, U_i at the boundary of the last cell (adjacent to the wall) are determined as for the case of a stationary impermeable wall (the velocity is equal in absolute value, but opposite in sign)

Figure 2 – Block diagram of the modified algorithm for calculating hydrodynamic parameters of impulse propagation in the well

3. Results and discussion

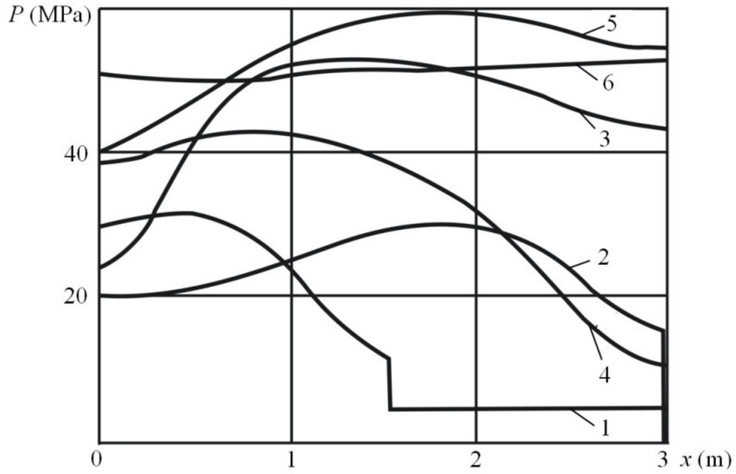
Calculations of hydrodynamic parameters generated by the oscillation source in the well (including the coordinate of the boundary of the oscillation source cavity, pressure at this boundary, pressure in different cross-sections along the length of the well and pressure at its bottomhole) are given for different duration of the impulse impact t_i (Table 1). The pneumodynamic impulse was chosen as the impulse impact on the liquid, in which multiple expansion and compression (pulsation) of the oscillation source cavity occurs.

Table 1 – Correspondence between calculation variants and impulse impact parameters

No variant	1	2	3	4	5	6	7	8	9	10	11	12
t_i, ms	4	3	2	4	3	2	4	3	2	4	3	2
L, m	1	1	1	3	3	3	5	5	5	20	20	20

The diameter of the well, in which the pulses were simulated, was chosen to be 105 mm, which is a typical size for gas extraction wells. The distance from the impulse impact zone to the bottomhole varied within the range of 1–20 m. The initial pressure in the well was taken to be 5 MPa, which corresponds to a depth of 200 m. The correspondence between the numbers of the calculation variants and the impact parameters is given in Table 1, where t_i is duration of the impulse impact, L is the distance to the bottomhole. For the calculation, the maximum time was chosen to be not less than the time corresponding to six reflections of compression waves from the bottomhole and the boundary of the oscillation source cavity. As a rule, within this time interval, the maximum pressure in the well is reached, which was confirmed by the calculations.

The mechanism of pressure distribution in the liquid at different time points, which characterizes the main hydrodynamic processes along the length of the well, is given on the example of calculation variant No. 6 (see Table 1) and is described as follows (Fig. 3).



1 – t = 1.03 mc; 2 – t = 2.0 mc; 3 – t = 4.15 mc; 4 – t = 6.33 mc; 5 – t = 8.51 mc; 6 – t = 10.51 mc

Figure 3 – Pressure profiles in the well at different time points

At the moment of the first impulse, a disturbance wave separates from the oscillation source. Since the impulses follow one after another, the pressure increases, and a compression wave is formed in the liquid (t = 1.03 mc). After reaching the maximum value, the pressure in the oscillation source drops, and it becomes a source of extension waves for the liquid.

Meanwhile, the distance between the maximum in the compression wave and the disturbance front is reduced, and a shock wave is formed. The parameters of the shock wave increase gradually with distance from the oscillation source, which is due to the action of the catching-up compression wave (t = 2.0 ms).

Further, the shock wave and then the compression wave and the extension wave arrive at the bottomhole. Pressure there increases, while reflected waves begin to propagate back towards the oscillation source. Before the reflected waves return to the bottomhole, a second compression wave, formed by the second impulse from the oscillation source, starts travelling in the liquid towards the bottomhole. This second compression wave arrives at the bottomhole after the extension wave and causes further pressure increase (t = 4.15 ms).

The compression wave reflected from the bottomhole reaches the wellhead and is reflected again by the extension wave, forcing the oscillation source to compress. This extension wave travels through the well and reduce the pressure (t = 6.33 ms).

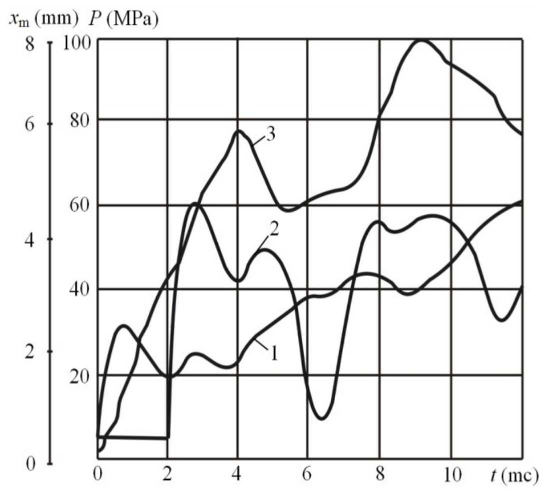
However, the compression of the oscillation source leads to pressure increase within it. The oscillation source begins to expand again, and a new compression wave is formed in the liquid (t = 8.51 ms). Then the processes qualitatively repeat.

As it is seen from the calculation results in Fig. 3, the impact at the bottomhole occurs as alternating pressure impulses (at t = 2 ms the pressure is P = 15 MPa; at t = 4 ms the pressure is 43 MPa; at t = 6 ms the pressure is 12 MPa; at t = 8 ms the pressure is 55 MPa). Such short-term high pressure fluctuations improve the filtration properties of the bottomhole zone. After 10 ms of impact (curve 6), the pressure in the well stabilizes and is equal to 50 MPa.

The dependence of the pressure in the oscillation source, the pressure at the bottomhole, the coordinate of the boundary of the oscillation source cavity over the time is shown in Fig. 4. The graphs show that the gas-filled cavity expands and reaches 6 mm in size during the first impulse within 4 ms, then compressed to 4.5 mm, and during the second impulse expands again to 8 mm. This behavior results from energy supply to the oscillation source, causing pressure to rise during the first impulse up to 30 MPa, then decrease, and rise again during subsequent impulses up to 60 MPa. Such pressure fluctuations at the cavity boundary cause corresponding pressure fluctuations at the bottomhole from 55 MPa to 12 MPa.

It should be noted that a comparison of the experimental data obtained in [21] and the calculation results using the proposed method showed that the calculated minimum coordinate of the boundary of the oscillation source cavity (corresponds to the time *t* =5.7 ms in the figure) may be underestimated by up to 20%. However, the difference between the experimental [21] and the theoretical values of the second maximum (*t*=9.1 ms) does not exceed 10%.

It should be expected that the value of the second maximum pressure at the bottomhole (*t*=4.8 ms), caused by the arrival of the second compression wave, and the values of the following local maxima may be overestimated because the mathematical model of the oscillation impulse propagation in the liquid does not account changes of thermodynamic parameters in the oscillation source, energy losses due to the liquid thermal conductivity, and changes in the stiffness of the well walls.



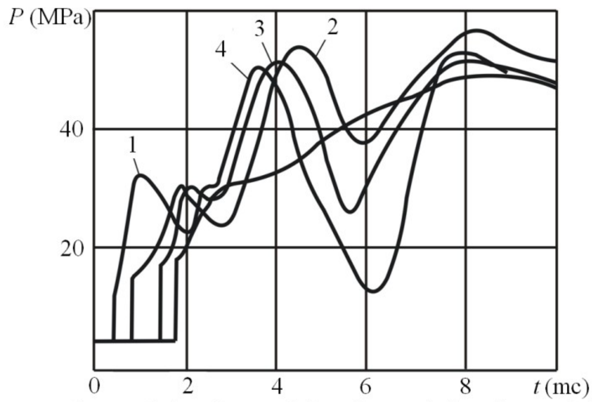
1 – P_m; 2 – P_f; 3 – x_m

Figure 4 – Dependences of the pressure at the boundary of the oscillation source P_m, the pressure at the bottomhole P_f and the coordinate of the boundary of the oscillation source cavity x_m over time for variant No. 6

To assess the impulse impact through the well on the surrounding rock mass, it is important to determine the pressure changes in cross-sections of the well located at different distances from the oscillation source. Such dependencies for variant No. 6 are shown in Fig. 5. The pressure in the first compression wave is 30 MPa, and then decreases to 25 MPa. In the next wave, the pressure increases to 50–55 MPa and decreases again. Notably, as the wave approaches bottomhole, the pressure fluctuations in the first impulse decrease, and in the second impulse, on the contrary, increase. This is explained by the influence of waves reflected from the bottomhole.

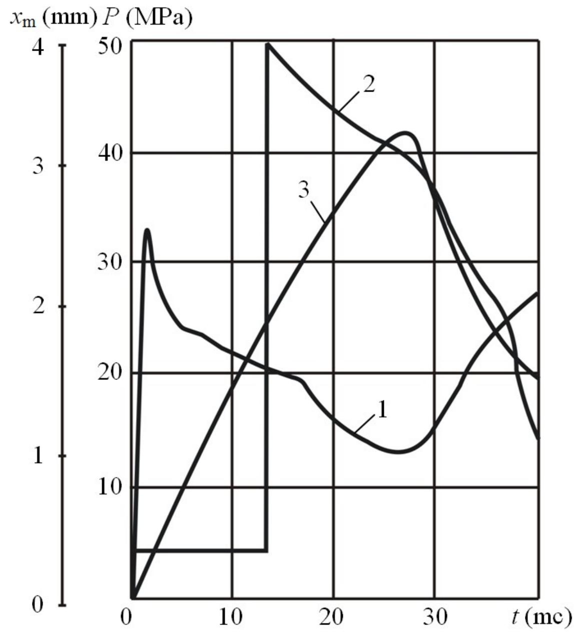
These pressure fluctuations are caused by the hydrodynamic processes described above. Pressure maxima after t = 6 ms should be considered overestimated for the reasons mentioned earlier. As the distance from the oscillation source to the bottomhole increases, the pressure-time dependencies in the different cross-sections change not only quantitatively but also qualitatively.

Fig. 6 shows similar curves for variant No. 12 (see Table 1), where the distance from the oscillation source to the bottomhole was 20 m. In this case, the expansion of the cavity lasts 27 ms, and its maximum size does not exceed 3.2 mm, after which it decreases. Pressure fluctuations at the cavity boundary are also weakly expressed: the maximum pressure is 33 MPa after 2 ms from the beginning of the impact and then slowly decreases to 13 MPa at the time point 26 ms. The compression wave arrives at the bottomhole after 13 ms, reaching 50 MPa, after which pressure decreases without fluctuations. That is, at large distances from the oscillation source, the impulse impact on the bottomhole is just a single event, which is not enough to improve the filtration properties of the bottomhole zone. This necessitates repeating the impulse treatment.



1 – x = 0.6 м; 2 – x = 1.2 м; 3 – x = 1.8 м; 4 – x = 2.6 м

Figure 5 – Pressure dependence on time in different cross-sections along the length of the well for variant No.6



1 – P_m; 2 – P_f; 3 – x_m

Figure 6 – Dependences of the pressure at the boundary of the oscillation source P_m, the pressure at the bottomhole P_f and the coordinate of the boundary of the oscillation source cavity x_m over time for variant No. 12

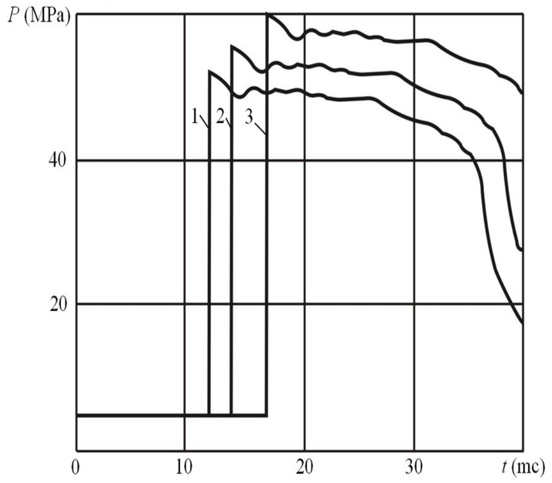
Therefore, this study investigated the influence of the duration of the oscillation source impulse on the process parameters at different distances to the bottomhole. The key parameters significantly determining the hydrodynamic processes in the well are the pressure in the oscillation source cavity and the coordinate of its boundary, the pressure on the bottomhole and the distance to it. Analysis of the obtained data shows that the differences in the pressure maxima that arise in the well due to the changes of the impulse duration are insignificant for the studied distances to the bottomhole. For example, when the distance to the bottomhole was 20 m at t_i=2 ms, the maximum pressure at the bottomhole was 51 MPa, and at t_i=4 ms – 57 MPa. That is, the difference did not exceed 12%. At shorter distances, the difference is even smaller. This is explained by the fact that the oscillatory processes in the oscillation source have a low decay decrement in the implemented impulse impact mode. Thus, there is no point in spending energy on increasing the duration of the impulses.

At the same time, as the distance from the oscillation source to the bottomhole increases, the change in the pressure at the bottomhole does not have a pronounced oscillatory character (single impulse). This necessitates repeating the impulse treatments of the rock mass to intensify gas release from it.

Modeling of physicochemical impact is implemented by changing the initial conditions of the model. For instance, when surfactants or polymers are used as the working liquid, the initial liquid density ρ_0 and the speed of sound in it a_0 decrease or increase, respectively, which affects the hydrodynamic parameters of impulse propagation in the well.

For example, the use of surfactants as a working liquid under the impulse impact creates the following initial conditions: $\rho_0 = 950 - 990\ kg/m^3$, $a_0 = \sqrt{\frac{Bm}{\rho_0}} = 1480 - 1510\ m/c$, and the use of polymers – $\rho_0 = 1010 - 1100\ kg/m^3$, $a_0 = 1410 - 1470\ m/c$ [22].

The calculated pressure results at the bottom of well 20 m long during impulse impact, using liquids with different densities, are shown in Figure 7. Increasing liquid density raises the pressure at the bottomhole from 55 MPa to 60 MPa, while the impulse arrival time increases from 12 ms to 17 ms correspondingly. In the example considered (distance of 20 m), the oscillatory processes are weakly expressed, but at a shorter distance, repeated pressure fluctuations from maximum to minimum increase by a factor of 4.5.



1 – surfactants; 2 – water; 3 – polymer

Figure 7 – Pressure at the bottomhole when using different working liquids

The graphs show that as a result of using different chemical compositions as a working liquid, the amplitude and the arrival time of the impulse at the bottomhole change. Specifically, when using surfactants, the impulse amplitude at the bottomhole is lower, and the time of its arrival is shorter compared to using technical water. The use of polymers gives the opposite result – later impulse arrival at the bottomhole, though its amplitude is 5–10% higher than when the impulse propagates in water.

5. Conclusions

1. A mathematical model and an algorithm are substantiated and proposed for calculating the parameters of hydroimpulse treatment of gas-extracting wells to intensify gas release using different physicochemical compositions of the working liquid. The approach differs by taking into account the specific power of the oscillation source per unit of the well cross-sectional area and by the layer-by-layer calculation of the liquid density and the wave velocity during the passage of impulses of different durations. The calculations showed a 10–20% discrepancy between the known experimental and obtained theoretical values.

2. The mechanism of pressure distribution in the liquid at different time points is established, which characterizes the main hydrodynamic processes along the length of the well. Its essence lies in the fact that a disturbance wave is separated from the oscillation source and a compression wave is formed in the liquid. After reaching its maximum, the pressure in the oscillation source cavity drops and becomes a source of extension waves for the liquid. A shock wave is formed in the compression wave. First, the shock wave, then the compression wave and the extension wave arrive at the bottomhole, while the reflected waves propagate towards the oscillation source. These processes qualitatively repeat with subsequent pulses.

3. The influence of the duration of the oscillation source impulse on the parameters of the process of hydrodynamic treatment of the well at different distances from the bottomhole is researched. It is found that differences in pressure maxima generated in the well at different pulse durations are insignificant. For example, at a 2 ms impulse duration, the maximum pressure at the bottomhole is 51 MPa, and at 4 ms - 57 MPa. Therefore, there is no point in spending energy on increasing the pulse duration. However, with increased distance from the oscillation source cavity to the bottomhole, the pressure variation loses its oscillatory character (single impulse), necessitating repeating impulse treatments for effective gas release intensification.

4. As a result of using different chemical compositions as a working liquid, the impulse amplitude and time of its arrival at the bottomhole change. When using surfactants instead of water, the impulse amplitude and time of its arrival at the bottomhole decrease. The use of polymers gives the opposite result - the time of impulse arrival at the bottomhole increases and its amplitude is 5–10% higher compared impulses in water.

5. The results of the calculations demonstrate that during hydroimpulse treatment of a gas extraction well with the aim to intensify gas extraction, it is advisable to control the state of its bottomhole zone both by adjusting the impulse impact parameters and by using different physicochemical compositions as a working liquid.

Conflict of interest

Authors state no conflict of interest.

REFERENCES

1. Krukovskaya, V.V. and Krukovskiy, D.A. (2017), “Method of calculation parameters of coupled processes of coal-rock massif deformation and methane filtration”, *Geo-Technical Mechanics*, vol. 133, pp. 123–135

2. Krukovska, V.V. and Krukovskyi, O.P. (2023), “Formation of the near-face stress field under the influence of natural and technological factors”, *Geo-Technical Mechanics*, vol. 165, pp. 97–116. https://doi.org/10.15407/geotm2023.165.097

3. Klets, A.P., Makeiev, S.Yu., Ivanov, V.P. and Makarenko, S.V. (2002), “Features of intensification of methane extraction by surface degassing borehole”, *Geo-Technical Mechanics*, vol. 37, pp. 93–96

4. Sofiyskyi, K.K., Prytula, D.O., Stasevych, R.K., Ahaiev, R.A. and Smirnov, O.P. (2020), “Principal possibility of using wave method of intensification of methane inflow through surface degassing boreholes”, *Geo-Technical Mechanics*, vol. 150, pp. 98–105. https://doi.org/10.15407/geotm2020.150.098

5. Zberovskyi, V., Vlasenko, V., Petukh, O., Kyrychenko, M., Zbierowski, P. and Kustra, A. (2024), “Hydroimpulse impact in the technological cycle of constructing preparatory drifts: evaluation and economic efficiency”, *Geo-Technical Mechanics*, vol. 168, pp. 17–24. https://doi.org/10.15407/geotm2024.168.017

6. Makeiev, S.Yu. and Andreiev, S.Yu. (2005), “Study of overcoming hydraulic resistance during methane extraction from a surface degassing borehole”, *Geo-Technical Mechanics*, vol. 54, pp. 37–41

7. Prytula, D.A., Agaiev, R.A., Sofiiskyi, K.K. and Novoseltsev, V.V. (2015), “Intensification of coalbed methane recovery by pneumohydrodynamic impact with use of carbonaceous agents”, *Geo-Technical Mechanics*, vol. 123, pp. 3–11. http://jnas.nbuv.gov-.ua/article/UJRN-0000846425

8. Zberovskiy, V.V., Vasilyev, L.M., Zhulay, Yu.A., Polyakov, Yu.Ye., Narivskiy, R.N. and Pazynich A.V. (2016), "Development of method for calculating parameters of hydroimpulse machine operating in the prone-to-outburst coal seams", *Geo-Technical Mechanics*, vol. 130, pp. 92–106

9. Barenblatt, G. I. and Zel'dovich, Ya. B. (1972), "Self-similar solutions as intermediate asymptotics", *Annual Rev. of Liquid Mech.*, vol. 4, pp. 285–312

10. Batchelor, G.K. (2000), *Introduction to Liquid Dynamics*, University Press, Cambridge, United Kingdom.

11. Dresner, L. (1983), *Similarity Solutions of Nonlinear Partial Differential Equations*, Pitman, Boston, USA

12. Sedov, L. I. (1988), *Metody podobiya i razmernostey v mekhanike* [Methods of similarity and dimensions in mechanics], Nauka, Moscow, USSR.

13. Brushlinsky, K. V. and Kazhdan, Ya. M. (1963), *Ob avtomodel'nykh resheniyakh nekotorykh zadach gazovoy dinamiki* [On self-similar solutions of some problems of gas dynamics], Nauka, Moscow, USSR.

14. Galiev, Sh.U. (1981), *Dinamika gidrouprugoplastncheskikh sistem* [Dynamics of hydroelastic-plastic systems], Naukova Dumka, Kyiv, Ukraine.

15. Atanov, G.A. (1979), *Osnovy odnomernoy nestatsionarnoy gazodinamiki* [Fundamentals of one-dimensional non-stationary gas dynamics], Vishcha shkola, Kyiv, Ukraine.

16. Cole, R.H. (1948), *Underwater Explosions,* Princeton University Press, Princeton, New Jersey, USA, available at: https://archive.org/details/underwaterexplos0000robe/page/n5/mode/2up (Accessed 30 March2025).

17. Sedov, L. I. (1976), *Mekhanika sploshnoy sredy* [Continuum Mechanics], Nauka, Moscow, USSR.

18. Godunov, S.K., Zbrodin, A.V., Ivanov, M.Ya., Kraiko, A.N. and Prokopov, G.P. (1976), *Chislennoye resheniye mnogomernykh zadach gazovoy dinamiki* [Numerical solution of multidimensional problems of gas dynamics], Nauka, Moscow, USSR.

19. Semko, A.N. (1976), *Raschot ul'trastruy s otkolami* [Calculation of ultrajets with spalls], Donetsk, Ukraine/

20. Ulanov, N.G. (1977), "Numerical solution of the problem of the impact of liquid jets with a non-flat head on an obstacle", *Works on Continuum Mechanics*, vol. 1, pp. 68–72

21. Golovko, Yu.N. (1982), *Chislennoye issledovaniye gidrodinamicheskikh protsessov pri podvodnykh iskrovykh razryadakh v ogranichennykh oblastyakh* [Numerical study of hydrodynamic processes in underwater spark discharges in limited areas], IGTM, Dnepropetrovsk, USSR.

22. Murdin, P. (2008), *Full Meridian of Glory: Perilous Adventures in the Competition to Measure the Earth*, Copernicus, New York, USA. available at: https://doi.org/10.1007/978-0-387-75534-2 (Accessed 30 March2025).

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РОЗРОБКА МАТЕМАТИЧНОЇ МОДЕЛІ І АЛГОРИТМУ РОЗРАХУНКУ ПАРАМЕТРІВ ГІДРОДИНАМІЧНОЇ ІНТЕНСИФІКАЦІЇ ГАЗОВИДІЛЕННЯ ІЗ СВЕРДЛОВИН

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Анотація. Робота присвячена обґрунтуванню математичної моделі розрахунку параметрів імпульсного впливу на привибійну частину свердловини через рідину з різними фізико-хімічними властивостями для підвищення вилучення газу з гірського масиву. Проаналізовано існуючі методи розрахунку, що описують гідродинаміку процесу поширення імпульсів в рідині. Запропоновано математичну модель розрахунку гідродинамічних процесів, що протікають у свердловині при імпульсному впливі, яка включає квазілінійні рівняння газової динаміки гіперболічного типу з початковими і граничними умовами, особливістю якої є врахування пульсацій джерела коливань. Розроблено блок-схему алгоритму розрахунку параметрів гідродинамічних імпульсів. Розглянуто лінійний перебіг рідини у свердловині між джерелом імпульсів та її вибоєм. Встановлено, що визначальними параметрами, які значною мірою впливають на гідродинамічні процеси в свердловині є її довжина, тиск в порожнині джерела коливань та координата її межі, а також тиск на вибої свердловини. Отримано динаміку розподілення профілів тиску по довжині свердловини в різні моменти часу при зміні вихідних параметрів імпульсного впливу.

Розраховані залежності тиску в джерелі коливань, на вибої свердловини і зміни координати межі порожнини джерела коливань від часу при різних режимах імпульсного впливу та виконано їх аналіз. Досліджено вплив тривалості імпульсу джерела коливань на параметри процесу за різної відстані до вибою. Встановлено, що керувати станом привибійної частини свердловини з метою інтенсифікації видобутку газу доцільно як параметрами імпульсного впливу, так і шляхом використання різних фізико-хімічних складів в якості робочої рідини. Варіювання складом рідини при імпульсному впливі призводить до зміни амплітуди та часу приходу імпульсу на вибій свердловини.

Результати досліджень можуть бути використані для розрахунку гідродинамічних процесів при імпульсній обробці газодобувних свердловин з метою інтенсифікації видобутку газу за рахунок зміни параметрів впливу та використання різних фізико-хімічних складів робочої рідини.

Ключові слова: газодобувна свердловина, інтенсифікація газовиділення, імпульсний вплив, гідродинамічні процеси.