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GASES AND LIQUIDS

Propagation of Pulsed Pressure during Electrohydraulic Drilling

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Abstract—We have analyzed the propagation of pulsed pressure produced by electric discharges in a heterogeneous liquid during well drilling. The pressure dynamics has been calculated based on theoretical analysis of the nonlinear process of the electrohydraulic effect in a heterogeneous medium. As a result of analysis, the time dependences of the relative pressure and shock front coordinate have been obtained.

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INTRODUCTION

The discovery and application of nontraditional energy sources determines national economics in many developed countries to a considerable extent. For this reason, the development of the power sector of Kazakhstan is characterized by reorganization of the fuel and energy complex. This is dictated by the rise in fuel prices on the world market and environmental problems. Implementation of new energy-saving technologies using nontraditional renewable energy sources is one of the approaches to solving these problems.

Various methods for power production in many countries are considered today in compliance with current tendencies. The thermal pump technology is one of the most effective methods. The high environmental effectiveness of this technology is due to the fact that it prevents discharge of greenhouse gas to the atmosphere. Therefore, the development of thermal pump technology rather than the replacement of old boilers in systems operating on gaseous and liquid fuels is one of the present problems.

For application of low-temperature thermal generation, it is necessary to prepare wells for installing heat exchangers of a thermal pump. Horizontal and vertical wells can be obtained using various drilling methods. The electrohydraulic method of rock destruction is preferable as compared to mechanical methods because of its low energy consumption and high efficiency [1–4].

This communication is aimed at calculation of pulsed pressure in heterogeneous media.

In this study, we consider the simulation of hydrodynamics of the electrohydraulic effect in which all processes (namely, the disturbance wave) are assumed to be isotropic; in addition, we assume that all other parameters vary identically in all directions. In our experiments, we discovered the possibility of concentrating the shock power with the help of a solid reflector, which is the inner part of the electrohydraulic drill prepared with a paraboloid shape.

1. COMPUTATION TECHNIQUE

Experimental data obtained by measuring the pulsed pressure in heterogeneous media under different conditions [5–8] necessitated analysis of the regularities in variation of pressure produced by waves reflected from the solid boundary for the maximal amplitude in a bubbling liquid.

In numerical calculations, we used differential equations that make it possible to determine the time variation of explosion pressure $P(t)$ and discharge size $x(t)$.

Our numerical calculations of the pressure dynamics based on thermodynamic analysis of the nonlinear process of the electrohydraulic effect in a heterogeneous medium were performed considering the effect of dispersion of the medium and the change in the channel geometry on the shock wave propagation by introducing specifying coefficients into the heat balance equation.

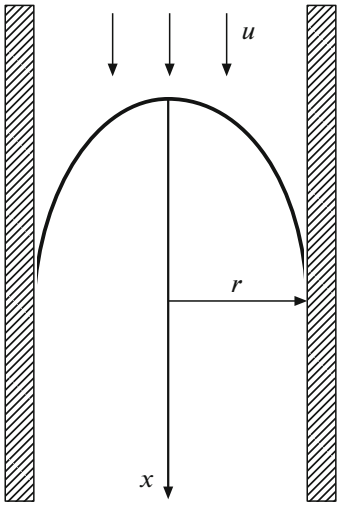

Fig. 1. Schematic diagram for calculating the volume of the discharge space.

Fig. 2. Electrohydraulic drill.

2. RESULTS OF NUMERICAL CALCULATION

The power released in the electrohydraulic effect can be written in form

$$N(t) = \frac{dQ(t)}{dt} = \frac{1}{k(\varphi) - 1}(VP' + k(\varphi)PV'), \qquad (1)$$

where $N(t)$ is the power, $Q(t)$ is the energy released during electric discharge, P is the pressure in the working medium, V is the discharge channel volume, and k is the polytropic exponent. Primes denote differentials with respect to time. At the first step, pressure P is equal to the maximal pressure at the shock front, which is determined from the Hugoniot condition:

$$P = \frac{2\rho_0}{k+1}u^2 = C_1u^2, \qquad (2)$$

where $C = \frac{2\rho_0}{k+1}$ is the coefficients considering nonlinear properties of the heterogeneous medium with density ρ_0 in the unperturbed state.

Velocity u of shock wave propagation can be determined using expression

$$u = \frac{dx(t)}{dt}, \qquad (3)$$

where x is the spatial coordinate.

The volume of space in which the shock wave propagates is equal to the volume of a certain paraboloid. If we direct the paraboloid axis along the direction of propagation of the shock wave, the base radius coincides with the working channel radius (Fig. 1). We assume that the high-voltage cable (electrode), which is a high-power source of pulsed pressure, is located between the focus and the double focus of the paraboloid. Then, the height of the paraboloid is directed along the x axis, and base radius r is determined by the coordinate perpendicular to the axis.

Working volume V of the discharge surrounding the channel, as well as the volume of the paraboloid, can be found using expression

$$V = C_2x^2, \qquad (4)$$

where $C_2 = \frac{2}{3}\pi r\tan\theta$ is the coefficient depending of the parameters of the channel along which the shock propagates, r is the radius of the working part of the tube, and θ is the angle whose tangent equals the ratio of the radius to the paraboloid height.

In the presence of walls bounding the working region in the form of a paraboloid, coefficient C_2 depends on the location of the central cable electrode, which accounts for the effect of limiting reflectors. Figure 2 shows the photograph of an electrohydraulic drill.

Using expressions (2)–(4), we transform Eq. (1) and obtain the following system for calculating the evolution of pressure and shock wave velocity:

$$\begin{cases} P' = \dfrac{k-1}{C_2}\dfrac{N(t)}{x^2} - 2k\sqrt{\dfrac{P^3}{C_1}}\dfrac{1}{x(t)} \\ x' = \pm\sqrt{\dfrac{P}{C_1}}. \end{cases} \qquad (5)$$

From the standpoint of hydrodynamics, the shock wave propagating along the axis of a paraboloidal reflector, where the pressure at the front is used for destruction of hard rocks, is a submerged turbulent jet, which has not been described theoretically yet. The results of modern investigations of the dynamics of turbulent processes are reported in [9–11].

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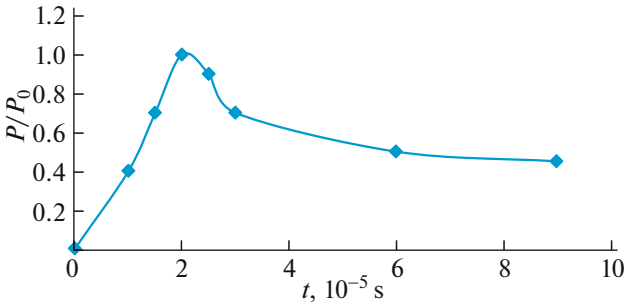

Fig. 3. Pressure in the discharge channel as a function of time.

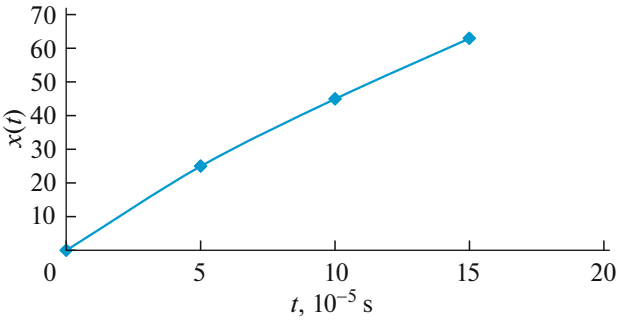

Fig. 4. Time dependence of the shock wave coordinate in the discharge channel.

The essence of the given approach is based on analysis of intermittence in turbulent mixing, which involves the alternation with time of the turbulent and unperturbed liquid at a fixed point. The entire jet is considered as a mixture of two liquids (turbulent and unperturbed). The probability of the emergence of turbulent liquid at a preset point is characterized by intermittency coefficient that is defined in terms of relative turbulence scale or velocity pulsation (alternation of laminar and turbulent forms of flow is known as intermittence).

For numerical calculation, we must specify the value of the function and its derivatives at the same point, at which initial time is zero ($t = 0$). The numerical results were obtained using the Pascal code; the curves describing the time dependences of relative pressure and coordinate of the shock wave and obtained using the MathCad packet are shown in Figs. 3 and 4.

CONCLUSIONS

The results of calculations and experimental data can be summarized as follows:

(i) the dynamics of pressure is calculated numerically based on thermodynamic analysis of the nonlinear process of the electrohydraulic effect in a heterogeneous medium;

(ii) it is found that the pulsed pressure amplitude increases in certain regions of the central cable (electrode) in the paraboloidal drill reflector; this fact indicates the extremely developed self-organized turbulence (i.e., combination of vortices formed upon reflection from solid reflectors), which is a sort of resonance of superimposed reflected shock waves;

(iii) during electric explosion, the shock energy propagates isotropically in all directions; with the help of a paraboloidal reflector, it can be concentrated in a certain preferred direction; the highest efficiency was observed when the cable electrode was located between the focus and the double focus of the paraboloidal reflector.

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