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SOLID STATE

On Electric-Pulse Well Drilling and Breaking of Solids

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Abstract—Research work has been carried out to determine the power-efficient regime of operation of an electric-pulse setup for breaking and crushing natural stones. The optimal energy and geometrical parameters of the method (dependence of the degree of breakdown of materials on the voltage and the electrode spacing in the switching unit) have been established. The proposed method makes it possible to effectively perform drilling in vertical wells for installing heat exchangers of thermal pumps.

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INTRODUCTION

The employment of alternative energy sources is considered in many countries to be a vital strategic resource that ensures the prospective development of their economy [1]. For this reason, the development of power engineering in Kazakhstan is characterized by radical reconstruction of the fuel-and-energy complex. This is due to the growth in prices of organic fuels in the global market and aggravation of environmental problems.

An efficient and optimal was of solving this problem is to develop power-saving technologies using low-potential heat of the ground [2]. Horizontal and vertical wells are used to install heat-exchangers of thermal pumps. A horizontal heat exchanger is installed near a building at a small depth. The use of these ground heat exchangers is limited by the parameters of available area [3]. A vertical heat exchanger effectively operates almost in all types of geological media except in grounds with a low thermal conductivity, such as dry gravel or dry sand [4–6]. Systems with vertical ground heat exchangers have become very popular at present. However, additional vertical heat exchangers of thermal pumps have to be installed in the basements or on the ground floors of buildings that have already been constructed, but not commissioned as yet.

Because of their large size, mechanical drills for boring vertical wells cannot be accommodated in basement or ground-floor rooms. Assembling and dismantling these installations requires considerable time.

In connection with this, an electric-pulse setup for vertical drilling has been designed and constructed at the Fluid Dynamics and Heat-Exchange Laboratory.

1. EXPERIMENTAL TECHNIQUE

The experimental area was located in the basement where the laboratory equipment was set up to study thermal processes that occur in wells during electric pulse drilling. Figure 1 shows the block diagram of the electric-pulse setup and the electric-pulse drilling tool. The inner part of the metal drill bit, which served as the cathode of the electric-pulse drill, had the shape of an elliptical paraboloid, which ensured the concentration of the pulsed pressure at one point. For this reason, a very high pressure was built at the ground surface when a discharge is initiated, which resulted in crushing of stones into small pieces.

To initiate an electric-pulse discharge, the cavity of the drill was filled with process water. The water flow carried away the small crushed rock pieces. Figure 2 shows the general view of the drill unit. Our experimental investigations made it possible to determine the optimal time and the number of spark discharges required for breaking natural stones and hard rocks. According to analysis carried out at the Interregional Department Tsentrkaznedra, the geological structure of the rocky ground in Central Kazakhstan region is hard for drilling; hence, additional laboratory tests were done on crushing of natural stones. A natural stone is a material with a complex structure formed by various minerals, subjected to considerable stresses. The hardness of the stones used in our experiments was 5–6 units on the Mohs scale [7].

[†] Deceased.

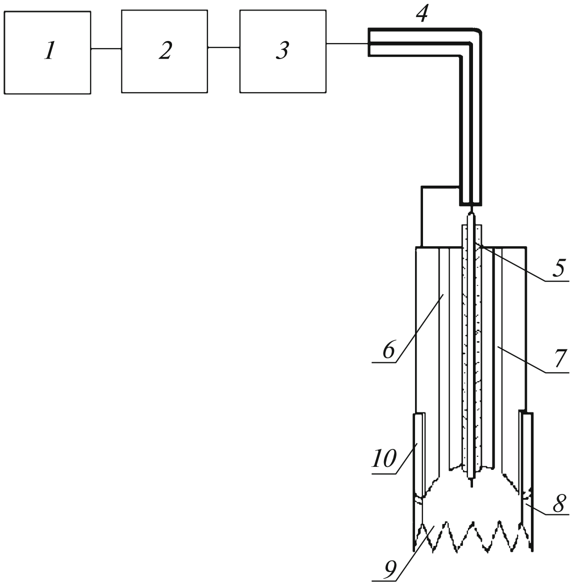

Fig. 1. Block diagram of electric-pulse setup and electric-pulse drill: (*1*) power supply; (*2*) high-voltage generator; (*3*) pulsed capacitor; (*4*) coaxial cable electrode; (*5*) central anode; (*6*, *7*) channels for supplying flushing liquid; (*8*) hole in the drill bit in the shape of an elliptical paraboloid; (*9*) bit teeth; and (*10*) drill bit.

Figure 3 shows a compact drilling unit of the experimental well used to install heat-exchanger tubes. Auger drilling was carried out for preparatory work at the initial stage, followed by electric hydraulic-pulse processing at the bottom of the well [8, 9].

Laboratory tests on the electric-pulse drilling of wells were carried out to a depth of 25 m.

After numerous tests, the processing of natural stones and selection of the regime of rock slab crushing were found to be essential. The experiments were carried out as follows. An electric-pulse drill was installed on the surface of a stone in a water-filled tub. After energizing of the setup, the number of discharges required for the onset of fracture was determined. Photographs in Fig. 4 show the samples of natural stones subjected to processing. After intense electric-pulse processing of natural stones, the samples were crushed into small pieces (Fig. 5).

During experiments, the electrophysical parameters of the setup were varied in the following intervals: U_{high} = 20–30 kV, C = 3 μF, l_{disch} = 7–12 mm, and L_{oper} = 25–35 mm.

The discharge energy in the working gap varied in the interval of E = 600–1350 J. The thickness of natural stones processed in the experiment varied in the range of 50–80 mm.

Fig. 2. General view of the drill unit.

2. RESULTS AND DISCUSSION

The effect of various factors on the efficiency of electric-pulse fracture of natural stones, including the variations in the fraction of energy released at the beginning of the breakdown, the time of energy supply initiating the breakdown, the variations in the electrode spacing, and the properties of natural stones, were investigated experimentally in the laboratory area. To determine the optimal regime of operation of the electric-pulse setup, we investigated the effect of the discharge energy on the efficiency of electric-discharge crushing of natural stones. The experiments were carried out on stones with different structures

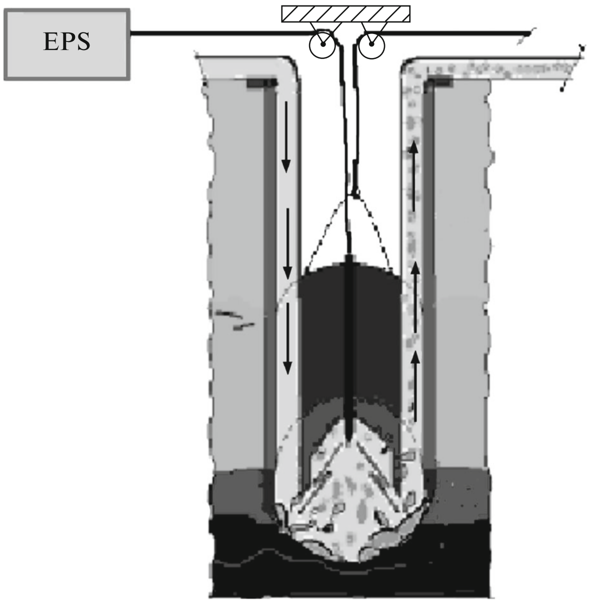

Fig. 3. Electric-pulse drilling.

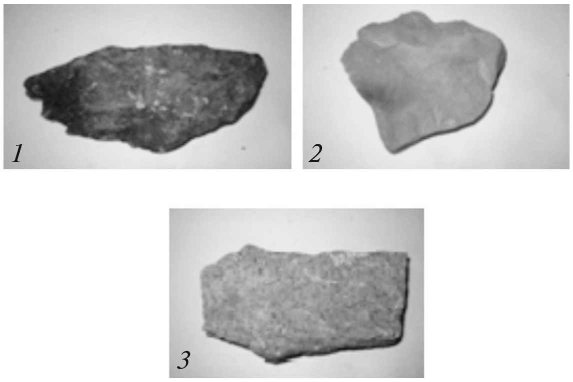

Fig. 4. Photographs of natural stone samples.

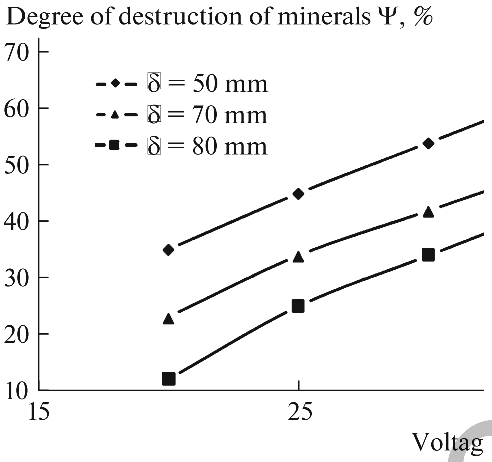

Fig. 6. Dependences of the degree of fracture of natural stones on voltage.

and compositions. Figure 6 shows the experimental results on the degree of breakdown of stones depending on the variation of stone thickness ($\delta \approx (50–80)$ mm) and initial voltage U_0 at a constant capacitance of capacitor banks. Figure 7 shows the results of experiments performed for the following parameters of the discharge circuit: $U_0 = 20$ kV and $C = 3$ μF. The electrode spacing varied in the range of $l = 7–12$ mm.

The results of laboratory experiments have shown that the maximal effect of breaking natural stones is observed at the following parameters of the electric-pulse setup: $U_0 = 30$ kV, $C = 3$ μF, and $l = 12$ mm. The optimal energy for breaking stones of thickness of 50–70 mm is 900 J, while a discharge energy of 1350 J is required to break stones with thicknesses of 80 mm. When the discharge energy increased to 1350 J, the complete fracture of stones was observed (Fig. 8). These results indicate the existence of certain optimal values for the electric discharge energy.

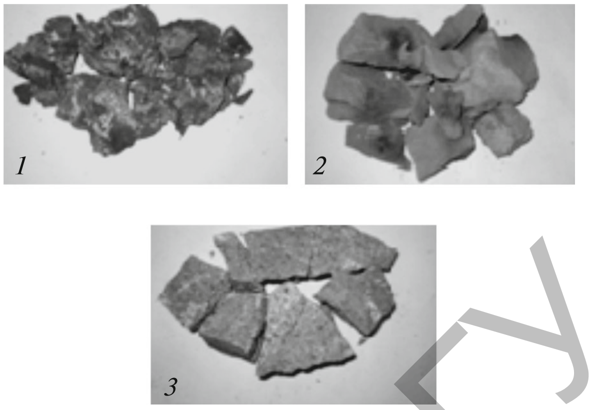

Fig. 5. Photographs of natural stone samples after electric-pulse processing.

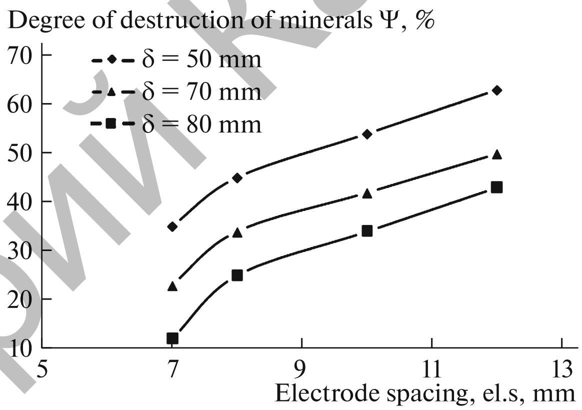

Fig. 7. Dependences of the degree of fracture of natural stones on the electrode spacing.

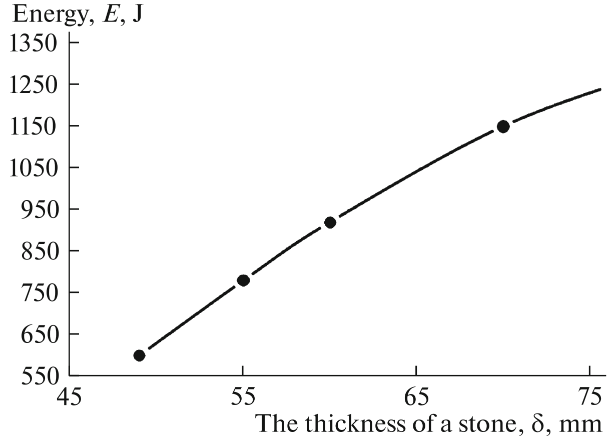

Fig. 8. Optimal energy of fracture of natural stones as a function of their thickness.

CONCLUSIONS

Based on the experiments, we have established the limits of the electrophysical parameters of the method, which correspond to the beginning of intense fracture of hard rocks. Special studies were performed in order to determine the optimal working conditions for an electric-pulse setup, and experiments were carried out in order to determine the effect of the discharge energy on the efficiency of the electric-discharge technique for breaking natural stones. The values of the maximal admissible values of the single-discharge energy depending on the shape and thickness of natural stones were determined. The quantitative dependences that characterize the onset of fracture of rocks with different thicknesses on the number and energy of discharges were also obtained.

The possibility of achieving drilling speeds higher than in traditional setups was demonstrated in experimental investigations. The electric-pulse breaking does not require special pressing of the electrodes to the bottom with a considerable force; for this reason, the wear of electrodes during electric pulse drilling is comparatively small, and only the cable electrode (which is a disposable material) is worn out.

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