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STUDY OF THE INFLUENCE OF ELECTROHYDRAULIC DRILLING PARAMETERS ON THE EFFICIENCY OF HARD SOILS DESTRUCTION

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Abstract. *This article examines several aspects of the electrohydraulic drilling method. It presents the results of an experimental study examining the influence of electrohydraulic drilling modes on the efficiency of breaking stone. A brief description and diagram of the experimental setup are provided. Quantitative relationships between the electrical parameters of the optimal mode of electrohydraulic drilling technology for breaking hard soils samples of varying thicknesses are determined. The experimental data confirm the feasibility of achieving significantly higher drilling speeds for vertical wells in hard soil compared to traditional methods.*

Keywords: electrohydraulic drilling, hydraulic pressure, pulse capacitor, well.

1. Introduction

Traditional methods still form the basis of the drilling industry due to the well-established nature of their equipment and technological processes [1-4]. Rotary, auger, core, and other drilling technologies remain effective and reliable under certain studied geological conditions; they are economically viable for drilling simple wells. New technologies, such as managed pressure drilling (MPD), are successfully used for drilling complex wells, allowing for consideration of soil rheological properties or changes in borehole geometry [1]. To improve efficiency, alternative methods are proposed, such as centrifugal drilling or combined technologies with additional automation, which provide more precise drilling and minimize harmful environmental impacts [2, 3]. Indeed, the current development of the petrochemical, energy, and geothermal industries requires the implementation of efficient and reliable well drilling methods in a variety of geological conditions. Traditional mechanical drilling methods encounter challenges when working in hard soil or heterogeneous formations. High mechanical loads, rapid wear of drilling tools, and significant energy consumption reduce the efficiency of traditional drilling technologies and increase operating costs.

Analysis of the current state of drilling technologies and the formulation of recommendations in the context of changing economic and environmental realities necessitates the integration of new technologies and scientific research to achieve a sustainable future in the energy sector [4]. In recent years, significant progress has been made in the development of electric pulse and hydropulse drilling technologies for the destruction of hard soils masses and deep geothermal formations. High-voltage pulsed electrical discharges are capable of generating powerful shock waves and plasma channels within the material structure, leading to the effective propagation of cracks and the destruction of crystalline formations such as granite and basalt. These technologies ensure selective destruction of rock mass with significantly less mechanical wear compared to traditional drilling methods and have high potential for application in geothermal energy, mining, processing industries, and other industries [5–9]. Electrohydraulic drilling is a fundamentally new drilling method that has not yet been widely adopted in industrial practice; therefore, the study of its potential and practical application remains a pressing scientific challenge. One of the key advantages of this technology is the ability to use it in spatially confined environments, such as buildings, basements, and other confined spaces, where the use of traditional drilling equipment is often difficult due to the significant dimensions and complexity of classic drilling rigs. In addition, electrohydraulic drilling systems ensure long-term and reliable operation due to the absence of constant mechanical contact and friction between the system elements. Ease of maintenance and operation is achieved through the use of an accessible cable as the active element, which functions as a consumable electrode [10–12].

The electro-hydro-pulse (EHP) method is based on the use of high-voltage pulsed electrical discharges, the discharge of which in a liquid medium is accompanied by the formation of shock waves, cavitation phenomena, and high pulsed hydraulic pressures. These physical processes lead to the initiation and propagation of microcracks, change the properties and structure of solid stone, and lead to their destruction [13-18]. However, despite the promising characteristics of this technology, its practical implementation in drilling processes remains limited. One of the main reasons is the insufficient understanding of the optimal electrophysical parameters required for effective rock fracture. Furthermore, the response of geological materials to electrohydraulic pulses depends significantly on their physical and structural properties, such as density, mineral composition, electrical strength, and the presence of internal fracture systems. Therefore, experimental study of the interaction of high-voltage electrical discharges with various types of hard rock is essential for improving the efficiency of electrohydraulic drilling technologies.

This paper presents the results of an experimental study of the influence of electrophysical parameters of the discharge circuit on the efficiency of hard soil fracture during electrohydraulic drilling.

2. Experimental unit and measurement techniques

Compared with traditional drilling methods, electrohydraulic technology provides a more efficient and rapid destruction of hard soil formations encountered during the drilling of boreholes for the installation of heat exchangers. This is achieved by generating high-intensity shock waves in a liquid medium [7-9]. The electrohydraulic effect is the occurrence of a high-voltage electric discharge in a liquid medium. During the formation of an electric discharge channel in the liquid, a significant amount of energy is released in an extremely short time. A high-voltage pulse with a steep rise front initiates a number of physical phenomena, including the formation of ultra-high pulsed hydraulic pressure, electromagnetic radiation in a wide frequency range, which may include X-ray radiation, and cavitation processes [11-13].

The samples used in the experiments were solid fossilized soil fragments (of the hard soils) collected from the experimental site in the Karaganda region. Before the experiments, the samples were sorted by size and, if necessary, subjected to minor mechanical processing to achieve the required thickness. Electrohydraulic pulse phenomena, which underlie various electro pulse technologies, have been investigated in previous works by the authors [14]. Experimental studies were carried out using an electrohydraulic pulse setup, the diagram of which is shown in Fig. 1. From a design point of view, the electrohydraulic pulse system includes several functional units, including a control panel, a capacitor unit equipped with a protection system, and a pulse current generator connected to a switchboard.

The capacitor is connected to the positive (+) and negative (−) terminals, which are connected in parallel with the transformer. The alternating voltage passes through the series resistance of the transformer's primary winding, generating a high voltage in the secondary winding. This voltage is then rectified by a rectifier, and the resulting direct current is fed to the capacitor. As a result, the voltage on the capacitor gradually increases to a certain level, at which point the accumulated energy is transferred through the forming gap (FI) to the working zone of the electrohydraulic pulse drill (ED), where a high-voltage electrical discharge occurs in the liquid medium. This process is repeated at a specific frequency determined by the operating parameters of the electrical circuit. The pulse frequency depends on the transformer output voltage, the capacitor capacitance, and the distance between the electrodes in the forming gap.

The experiments involved natural stone samples, that is, a material with diverse structures formed from various natural minerals.

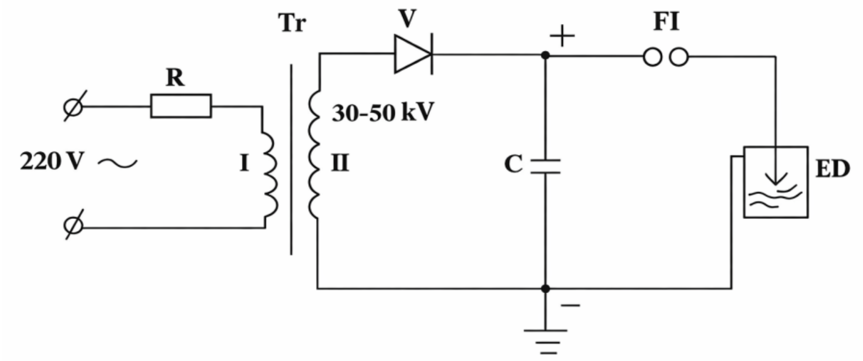


Fig. 1. Electrical diagram of the electrohydraulic pulse unit:
R — discharge resistor; Tr — high-voltage transformer; V — rectifier; C — pulse capacitor;
FI — forming gap (spark gap); ED — electrohydraulic pulse drilling machine.

There are involved samples of nature hard soils (stones) placed in a circular working cell; which the geometric parameters were determined by the design of an electrohydraulic drill. The working zone diameter for the drill's design was 115 mm. The working group height varied depending on the size of the samples being processed and was approximately 70–80 mm. The samples were placed in a working chamber filled with a liquid—ordinary process water—in which a production discharge was generated, generating shock waves. The experimental electrohydraulic drilling circuit is shown in Figure 2.

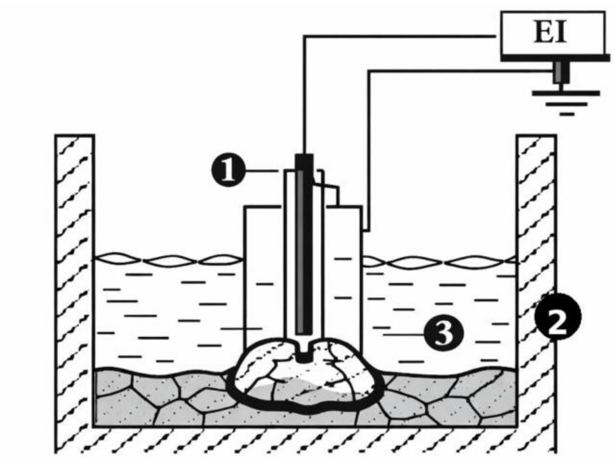
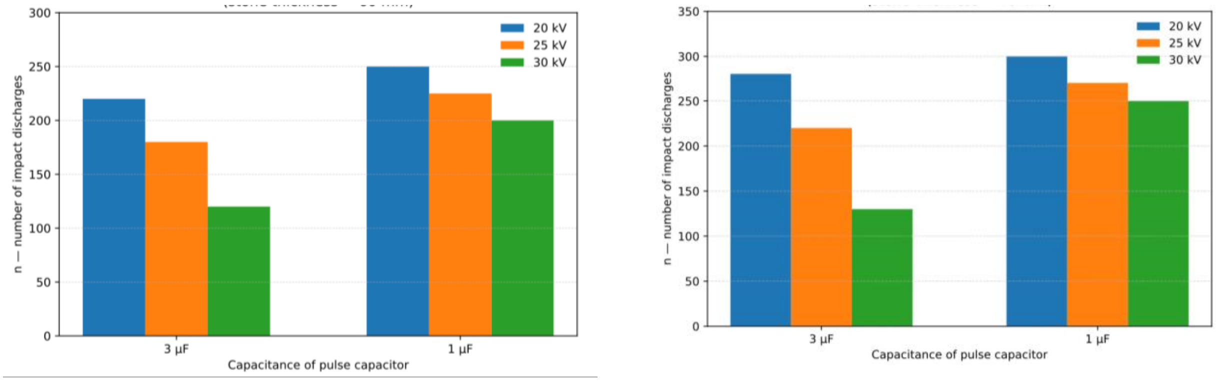


Fig. 2. Electrohydraulic drilling scheme:
1 — positive electrode; 2 — working chamber; 3 — hard soil particles.

This study examined hard rock samples from the Karaganda region of the Republic of Kazakhstan, as siltstone (a hard rock intermediate between clay and sandstone). The hardness of the natural rock samples subjected to high pressure testing was approximately 5-6 on the Mohs scale [13]. But in these experiments, no special methods were used to determine the structure and hardness of the soil samples. The destruction caused by the electro-hydro-pulse discharges, as well as the structure and density of the stones, were recorded visually, based on the actual destruction and crushing of the stones. During laboratory testing, it was necessary to ensure optimal drilling parameters at which the high pressure at the shock wave front leads to intensive destruction of the hard soil samples. The experiments were conducted at least three times under identical conditions. The average measurement error was 7-9%.

3. Results and discussions

Experiments were conducted on hard stone samples with varying structure and composition. The comparative graphs in Figure 3 (a, b) illustrate the relationship between the number of pulse discharges and the initial voltage U_0 at a constant capacitor bank capacitance for hard stone samples 60 mm (a) and 70 mm (b) thick. Based on the results of laboratory experiments, it can be concluded that the greatest efficiency in breaking natural stone using electric discharges is achieved with the following operating parameters of the high-voltage pulse generator discharge circuit: U0 = 35 kV, C = 3 μF, and an interelectrode distance of 12 mm.



a) b)

Fig. 3. Comparative graph of the number of shock discharges for different capacitors; thickness of the hard stone sample: a) 60 mm; b) 70 mm.

It was found that the most effective breaking of hard stone in a borehole occurs with a discharge circuit voltage in the range of 20–35 kV, a capacitance of 1–3 μF, and an interelectrode distance of 7–12 mm. Under these conditions, electrohydraulic pulses generate shock waves with sufficient energy to initiate and propagate cracks in the stone structure. The experiments determined the voltage influence (20-35 kV) discharge circuit on mineral stones destruction, and number and frequency of spark discharges required for electrohydraulic drilling at a given thickness of the hard stone soil layer (Figure 4).

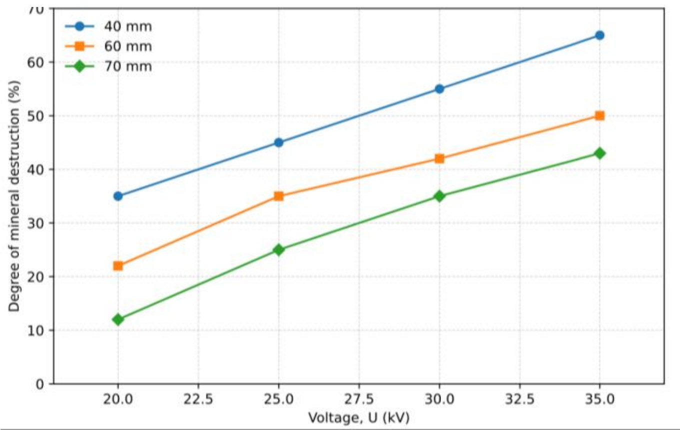


Fig. 4. Effect of discharge voltage on the degree of mineral destruction for different thicknesses of hard soil samples.

Based on the experiments, the range of electrophysical parameters at which intensive destruction of hard soil, particularly natural stone, begins was determined. The optimal energy required to destroy stone is in the range of 0.3–0.6 kJ. With an increase in discharge energy to approximately 612 J, complete destruction of the stone samples is observed (Figure 5). Based on the results, the optimal range of electric discharge energy for the most effective destruction of natural materials was determined. The depth of hard soil mass destruction increases proportionally to the number of pulsed discharges, as each discharge generates a pressure pulse that propagates through the material and intensifies the destruction of the structure and surface of hard soil. As the discharge intensity increases, so does the generated pressure, which intensifies the destruction process and, consequently, leads to an increase in drilling depth. The obtained results confirm that the electrohydraulic effect provides an effective mechanism for the direct conversion of electrical energy into mechanical energy by generating high-energy shock waves and cavitation processes in a liquid medium. A comparison with traditional mechanical drilling technologies shows that the electrohydraulic method offers a number of significant technological advantages. In particular, the absence of constant mechanical contact between the drilling tool and the hard soil mass significantly reduces mechanical wear of the equipment and increases the operational reliability of the system.

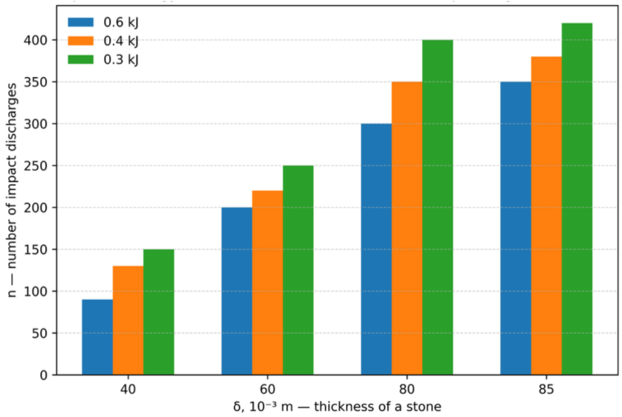


Fig. 5. Dependence energy level of hard soil destruction depending on the thickness of a stone.

Furthermore, electrohydraulic drilling rigs are characterized by a relatively simple design and compact dimensions, allowing their use in space-constrained environments where the use of traditional drilling equipment is difficult or impossible.

4. Conclusion

Based on the experimental studies, optimal electrophysical parameters were determined to initiate intensive destruction of hard soil using electrohydraulic pressure pulses. Test experiments demonstrated that hard soil sample destruction efficiency depends significantly on the electrical characteristics of the discharge circuit, including the initial voltage, the capacitance of the pulse capacitor, and the distance between the electrodes. The highest efficiency of hard soil destruction in the experiments was achieved with parameters of the order of U0 = 35 kV, C = 3 μF, and an interelectrode distance of 12 mm, which ensures the generation of powerful shock waves.

Electrohydraulic drilling technology provides high destruction efficiency, reduces specific energy consumption, minimizes wear on drilling tools, and enables efficient operation in hard, heterogeneous soils. Unlike traditional mechanical drilling methods, electrohydraulic technology ensures more efficient destruction of hard soils by converting electrical energy into shock wave energy, which reduces mechanical wear on equipment and lowers specific energy consumption. The novelty of this study lies in establishing the optimal parameters for electrohydraulic pulse action and identifying patterns of fracture in hard soils. The practical significance of these results lies in the potential application of this technology for shallow well drilling for ground heat exchangers in complex geological conditions, including hard soils. The presented experimental data can serve as a basis for further optimization of electrohydraulic drilling systems in future.

Conflict of interest statement

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

CRediT author statement

Shaimerdenova K.M.: Supervision, Methodology, Writing – review & editing; **Nussupbekov B.R.:** Conceptualization, methodology; **Schrager E.R.:** Data curation, Validation; **Akhmadiyev B.A.**: Investigation,Visualization; **Nakipova S.Zh.:** Investigation, Writing – original draft; **Rakhmankyzy A.**: Formal analysis, Data curation.
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