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Electrohydraulic drilling of rocks and research of processes of an erosion of metal part of electrode system of the drill

The article considers the advantages of electro-hydraulic method of drilling and the process of wear of drill electrodes during its operation. The processes of erosion at the metal part of electrode system of the electro-hydraulic drill have been studied; the dependence of the electrode wear rate on the number of pulses has been established. On the basis of experimental studies the authors have established bounds of electro-physical parameters of the method, within which the intensive destruction of solid rocks starts. Quantitative dependencies characterizing the beginning of the process of destruction of rocks of different thickness depending on the number and energy discharges have been defined.

Key words: heat pump, heat exchanger, electro-hydraulic drilling, electrode system.

Development of scientific and practical bases of implementation of energy-saving heat pump technology for heat and cold supply of residential, public and industrial premises on the basis of non-conventional and renewable energy sources is an urgent task today.

The heat exchanger of the heat pump is installed in the well holes for using soil and groundwater heat. A widely used method for making pits and well holes is drilling.

Currently, there are many kinds of drilling machines widely used in Kazakhstan. The existing drilling technologies of heat exchangers well holes are effective under soft ground conditions without hard rocks and stone slabs. Drilling to the depth of 25 meters with a diameter well holes up to half a meter with the above mentioned problems can be difficult [1].

Need for development of new technology, new highly efficient technological processes and equipment, means of mechanization and automation, has led to the research and development of a number of new techniques to disintegrate solids by drilling, based on different physical principles. Electric hydro-pulse drilling turned out one of the most promising methods, the essence of which is the destructive effect of electric pulse discharges in solid non-conductive and semi-conductive materials [2].

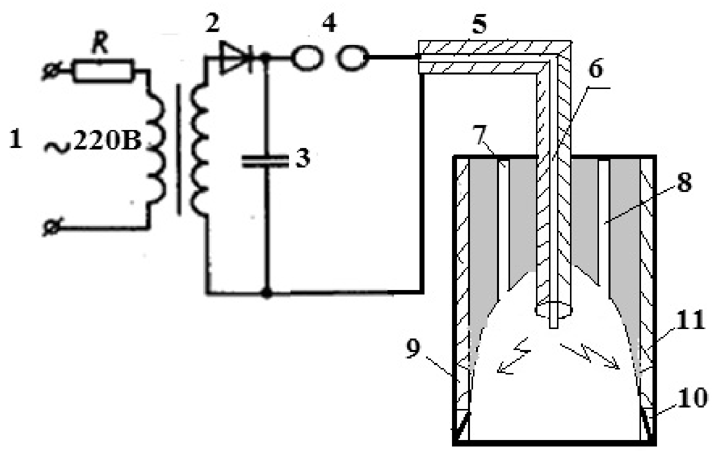
This paper deals with a new innovative way of making well holes using method of electric hydro-pulse drilling based on a unique phenomenon that is the way of direct conversion of electrical energy into mechanical energy of shock waves, efficiently destructing rocks at the well bottom.

Electro-hydraulic drilling is a fundamentally new way and has not yet found industrial application; the task of research and practical implementation of this technology remains important up to date.

The main advantages of the suggested technology are as follows: the opportunity to carry out operations under conditions of a limited space, long-term reliable operation due to the absence of rubbing and wearing parts of the plant and simplicity in operation and maintenance that is achieved by using as an active part an electrode cable, which is the only consumable.

This technology, as compared to traditional ones, allows more efficiently and in the short term to destroy obstacles in the form of solid rock by the impact of shock waves at high-voltage discharges in aquatic environment, in well holes drilling for installation of heat exchangers.

To form a pulse with a short front of the voltage applied to the discharge gap in a liquid the authors used a discharge gap in the air that is an air discharger; and to generate a pulse of certain energy they used energy storage electrical capacitor. In the laboratory of hydrodynamics and heat transfer of Karaganda State University named after academician E.A.Buketov, the authors have developed and tested an electro-hydraulic plant and a working area for drilling (Fig. 1).



1 — power supply; *2* — high-voltage generator; *3* — pulse capacitor; *4* — discharger;
5 — coaxial cable-electrode; *6* — centre electrode; *7* and *8* — water passages for injection the face;
9 — vent in the bit for gas outlet; *10* — teeth of the drilling bit; *11* — head of the drilling bit

Figure 1. Scheme of electro-hydraulic apparatus and electro-hydraulic drill

As a result of the experimental study the authors defined the optimal values of time and the number of spark discharges in electro-hydraulic drilling the stones, and determined the time at which destruction of stones and hard rock occurs during the drilling.

Using the experiment results the authors plotted the dependence graphs of the number of discharges on the thickness of the stone at different values of discharge energy (Fig. 2).

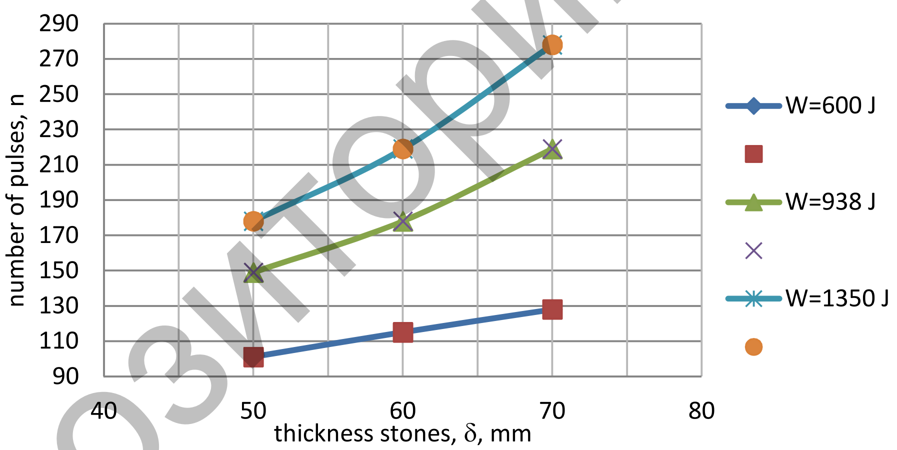


Figure 2. Dependence of the number of impact discharges on the thickness of a stone prior to crushing

The graph shows that at discharge energy of 600 J a stone can be destroyed to the thickness of 50–60 mm. The number of pulses is 275. The higher the discharge energy the thicker stones are destroyed; whereas the number of pulses required to break stones decreases. For example, at the discharge energy of 1350 J, it is possible to disintegrate 70 mm thick stones. This requires a smaller number of pulses that is of the order of 130 pulses [3].

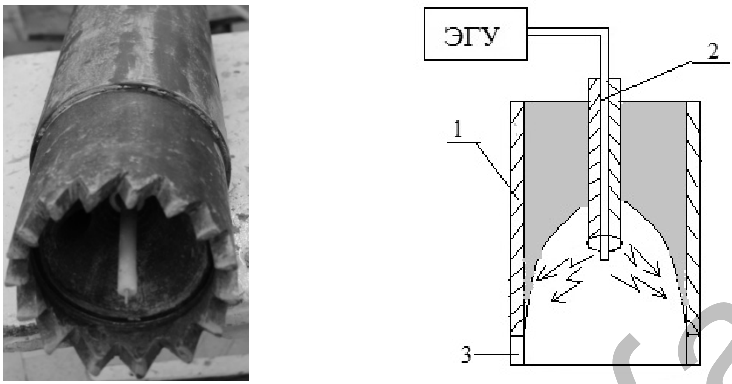
In the device for drilling well holes containing a source of pulse current, one electrode is in the form of the bare cable cord connected to the positive output of pulse current source, and its negative output is connected to the electro-hydraulic drill crown. This electrode structure makes a certain convenience when drilling heat exchanger well holes of heat pumps.

Forces caused by discharge due to hydraulic impact and flow force, as a result of redistribution of velocities, stimulate self-centering of the electrode cable. During continuous operation the central bare cord of the electrode cable is shortened due to erosion, and the insulator of its end breaks down. Insulation is basically breaks down along the central cord and the device loses its efficiency. In this case, after the solid rocks fracture it is necessary to periodically tinker the operating tip of the electrode cable giving it original shape.

To study the process of the electrodes wear under an electro-hydraulic processing, a special stand has been assembled, that is a plant for fixing and testing tubes made of different metals.

The technique of testing of inner cavity of tubes is based on taking pictures of a microscope at different magnifications with subsequent analysis of the grain size and porosity determination.

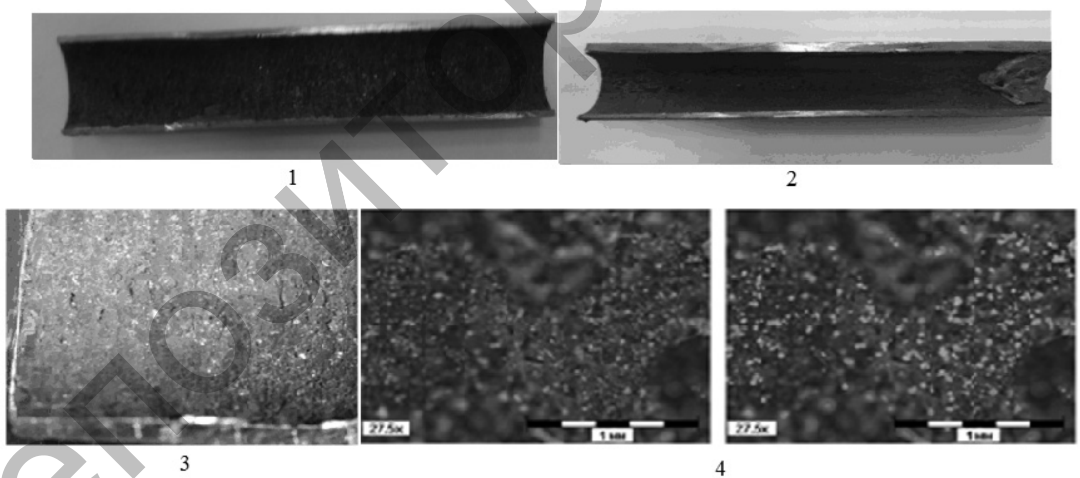
The exterior view of an electro-hydraulic drill and the scheme of the stand for electrode wear process study are shown in Figure 3.



1 — a tubular exterior side of the drill, the negative electrode;
2 — a central positive electrode; *3* — drill teeth

Figure 3. The exterior view of an electro-hydraulic drill
and the scheme of the stand for electrode wear process study

The negative electrode is a tubular exterior side of the drill. The inside of the drill is modeled as pieces of tubes. Figure 4 shows the pictures of tube pieces before processing scaled up as 1×1, 1×6,5 and 1×100 times.



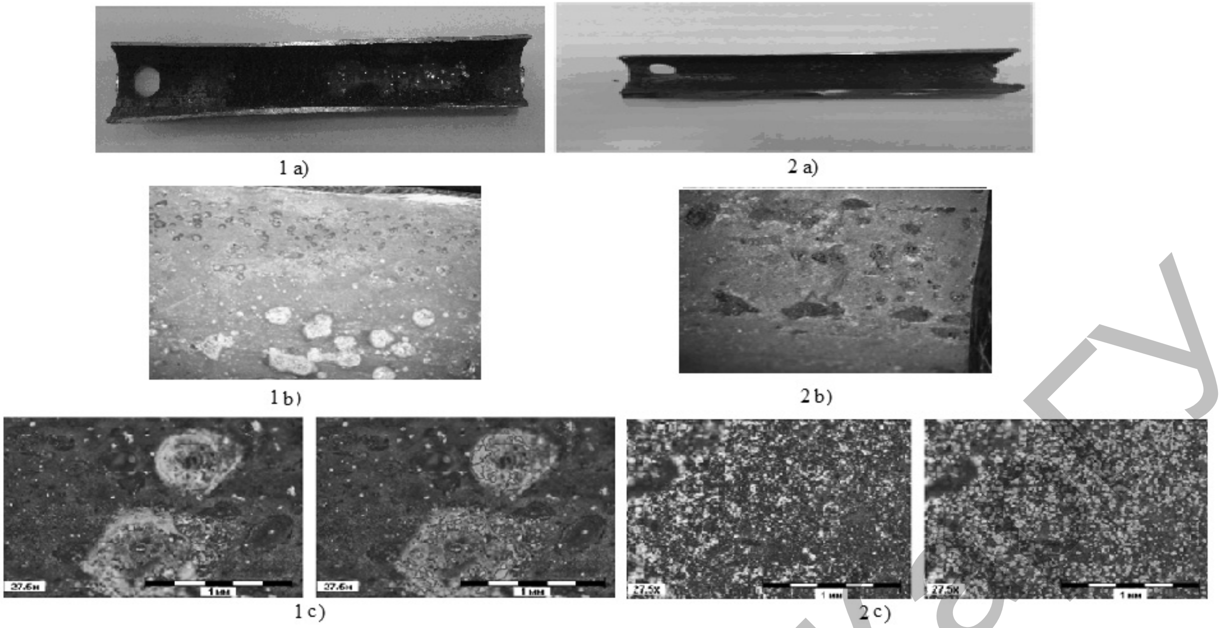
1 — a copper tube; *2* — a steel tube; *3* — a steel tube magnified by 6.5 times;
4 — a steel tube magnified by 100 times

Figure 4. Pictures of tubes before processing

Figure 5 shows the pictures of the tubes microstructure magnified by 1×6,5 times, and 1×100 times after processing.

The pictures show that after the electro-hydraulic processing, the microstructure of the negative electrode does not change and scuff.

Figure 6 shows the porosity of the tubes before and after processing magnified by 100 times.



1a — a copper tube; *1b* — a copper tube magnified by 6.5 times; *1c* — a copper tube magnified by 100 times;
2a — a steel tube; *2b* — a steel tube magnified by 6.5 times; *2c* — a steel tube magnified by 100 times

Figure 5. Pictures of tubes after processing

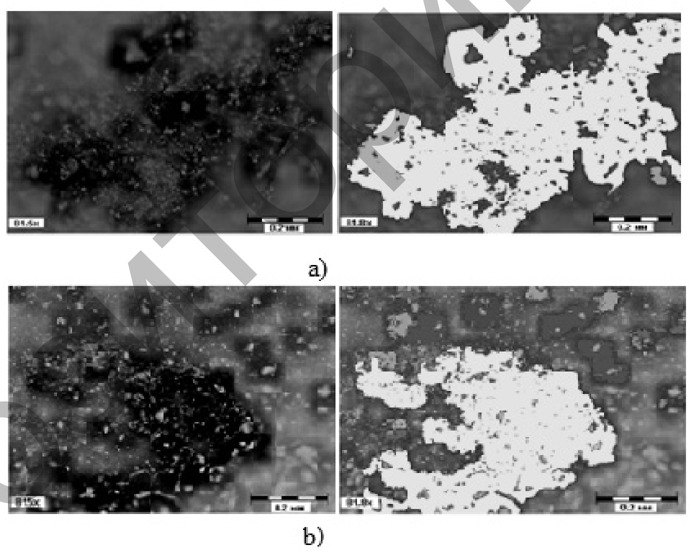


Figure 6. Pictures of the porosity of tubes *a*) before and *b*) after processing magnified by 100 times

After the electro-hydraulic processing burns of different types were found on the tube surfaces: they were in the form of points, spots and of prolate form. The metal surface in areas of burns was rougher than it had been initially; the maximum height of asperities reached 0.086×10^{-3} m. The concentration of point burns ranged within 1/cm^2 and depended on the position of the movable electrode at the time of its passage through the tube and its speed. In the burn areas the surface was flowed, inclusions of copper (electrode material) of rounded shape with a diameter up to 0.055×10^{-3} m were seen.

While in operation, each discharge is accompanied by electrode erosion wear, the value of which depends on the energy of the pulse voltage, electrode material, etc. In the course of operation, the electrode cable of the electro-hydraulic drill typically breaks down. The result of the positive electrode wear is shown in Figure 7.

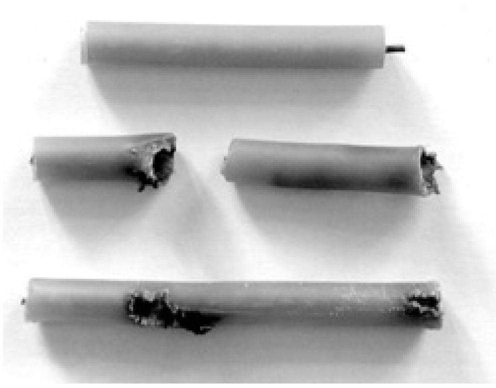


Figure 7. The electrode cable and its typical fractures in the course of operation

Studies show that the erosive wear of metals is different. For example, the mass of metal carried away from the electrode during a discharge can be defined by the formula [4]:

$$m_в = \frac{k_d u_e \alpha}{\dfrac{3c_p\left(T_m - T_0\right) - r_f}{k_r} + r_v},$$

where k_d — is the coefficient taking into account the effect of the diameter of the conducting rod on erosion; k_r — is the material release factor during a discharge; u_e — is the equivalent energy potential; α — is the integral of the discharge current modulus; c_p — is the specific heat capacitance of the electrode rod material; T_m, T_0 are the melting point and the initial temperature of the electrode rod material; r_f, r_v are the specific heat of fusion and vaporization of the electrode material.

Similar studies were conducted by the electro-hydraulics design office of the Academy of sciences of Ukraine. At the pulse energy of 10 kJ and 10 kV voltage, the length of the positive electrode steel rod of 10 mm diameter was shortened by 1 mm after 50 pulses. A rod with a diameter of 16 mm at the energy of 100 kJ was shortened by 1 mm after every 10 pulses [5].

During the experiment, the dependence of the electrode wear rate on the number of pulses was defined (Fig. 8).

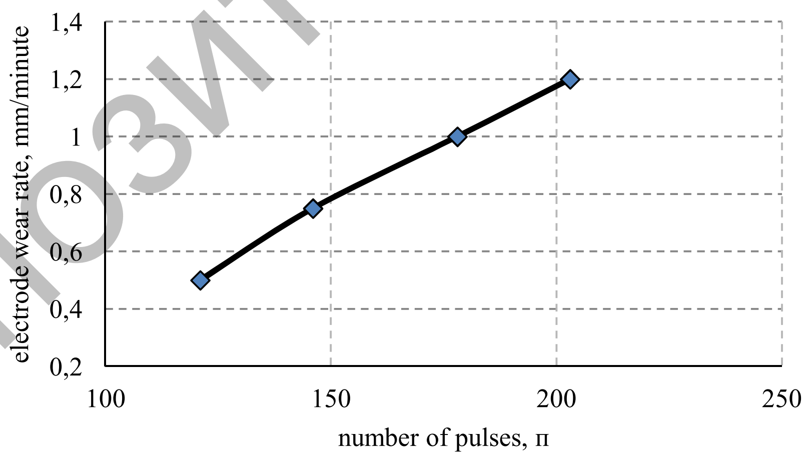


Figure 8. The graph of the dependence of electrode wear rate on the number of pulses

The experiments showed that at the pulse energy of 900 J and a voltage of 20 kV, the length of the positive electrode copper rod having the diameter of 2 mm is shortened by 1 mm after 121 pulses during 2 minutes and in 3 minutes after 178 pulses the length of the electrode is shortened by 3 mm. Thus, if we calculate the positive electrode erosion for these conditions, it turns out that the energy release in the initiated discharge gap of 900 joules of energy at a voltage of 20 kV is accompanied by a decrease in the volume of the electrode of about 3.14–9.42 mm^3.

Matching all the results, we can say the following.

It is experimentally proved that burns and inclusions of electrode material of the mentioned sizes have no impact on the tested tubes. The analysis of the results shows that the shock wave generated by a spark discharge within the range of pulse voltage values at a switching device does not affect the structure of the tube surface.

Thus, as compared with traditionally used plants, using the electro-hydraulic drill, the experimentalists achieved a higher drilling speed. The electric pulse destruction is implemented without using a drilling bit, it does not require special tightness of electrodes to bottom hole surface with considerable force; therefore, the wear of the electrodes at electro-hydraulic pulse drilling is relatively minor.

Using a result of the experimental study, the authors have defined the optimal values of electro-physical parameters, within which the intensive destruction of solid and super solid rocks starts. The dependence graphs characterizing the beginning of the process of destruction of rocks of different thickness depending on the number and energy discharges are plotted. The processes of erosion at the metal part of electrode system of the electro-hydraulic drill have been studied and micro-structural analyses of tubes with different properties before and after processing have been carried out. Using the experiment results the authors plotted the dependence graph of the electrode wear rate on the number of pulses. The exterior of the electro-hydraulic drill serving as a negative electrode does not wear out, and wear occurs only in the central electrode cable.

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Тау жыныстарын электрогидравликалық әдіспен бұрғылау және бұрғының электродтар жүйесінің металдық бөлігінің мүжілуін зерттеу

Мақалада электрогидравликалық бұрғылау әдісінің артықшылықтары мен бұрғының электродтары-ның мүжілу үдерісі қарастырылған. Электрогидравликалық бұрғының электродтар жүйесінің метал-дық бөлігінің эрозиялану үдерісі зерттелді. Электродтың мүжілу жылдамдығының импульс санына тәуелділігі алынды. Тәжірибелік зерттеулердің негізінде қатты тау жыныстарының қарқынды ұсақ-талу басталатын электрофизикалық параметрлері айқындалды. Қалыңдығы әр түрлі тастардың ұнтақ-талу үрдісі басталатын разряд саны мен энергиясына тәуелділігін сипаттайтын сандық заңдылықтар белгіленді.

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Электрогидравлическое бурение горных пород и исследование процессов эрозии металлической части электродной системы бура

В статье рассмотрены преимущества электрогидравлического способа бурения и процесс износа элек-тродов бура. Исследованы процессы эрозии металлической части электродной системы электрогид-равлического бура, получена зависимость скорости изнашивания электрода от числа импульсов. На основании экспериментальных исследований установлены границы электрофизических параметров метода, где начинается интенсивное разрушение твердых горных пород. Установлены количественные закономерности, характеризующие начало процесса разрушения пород разной толщины в зависимости от количества и энергии разрядов.

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