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PREPARATION OF WELLS USING AN ELECTROHYDRAULIC DRILL AND MODELING OF HEAT TRANSFER PROCESSES IN HEAT TRANSFER ELEMENTS OF A HEAT PUMP

Bektursin Akhmadiyev
Master of Physical Sciences*
Gaukhar Zhetimekova
Candidate of Technical Sciences, Senior Lecturer**
Moldir Duisenbayeva
Correspondent author
Master of Natural Sciences*
E-mail: m_o_l_d_i_r_89@mail.ru
Adilzada Sharzadin
Candidate of Pedagogical Sciences
Department of Transport and Logistics Systems**
Bekbolat Nussupbekov
Candidate of Technical Sciences, Professor*
*Department of Engineering Thermophysics
named after Professor Zh. S. Akylbayev**
**Karaganda Buketov University
University str., 28, Karaganda,
Republic of Kazakhstan, 100024

The article discusses the use of innovative electrohydraulic technology in the preparation of vertical ground heat exchangers to create heat supply using heat pumps. The discharge energy in the operating range varied E=900÷2600 J. The most economical mode of operation of the electrohydraulic installation is carried out with the following parameters: discharge voltage 30÷51 kV, capacitor bank capacity 2 μF and interelectrode distance 8÷15 mm. It is determined that the optimal energy of destruction of natural materials depends on their thickness. Based on the research, the limits of the electrophysical parameters of the approach were established, at which the concentrated destruction of hard rocks – the main stones – begins. The effective amount of energy for the destruction of stones with a thickness of 53 mm is 900 J. For stones with a thickness of 78 mm, there should be 2600 J. If to increase the energy of the discharges to 1837 J, the process of complete destruction of the stones is underway. Using an electro hydraulic drill, we have prepared vertical wells up to 25 m deep.

In the future, we have installed special temperature sensors along the length of the pipes, inside the well. Using a software product (Temp Keeper), data from temperature sensors are received in real time. This program allows to visually monitor temperature changes occurring at a local point. Temperature and time dependences are also obtained at coolant velocities of 0.2÷0.4 m/s. A significant decrease in the temperature in the well and at the outlet was observed at a coolant velocity of 0.35 m/s for one hour. The study conducted on the basis of the data obtained enables to achieve higher optimal drilling performance compared to conventional installations

Keywords: electrohydraulic drilling, borehole, heat exchanger, discharge voltage, fracture energy, modeling

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1. Introduction

To date, the issues of ensuring the rational organization of the processes of heat removal from the soil mass during the operation of a geothermal heat pump installation, issues of heat accumulation of soil are relevant. In this regard, the analysis of factors affecting the thermal regime of the soil acquires an important practical significance. Here it is necessary to take into account the mutual influence of thermal processes in the soil mass and processes in the ground heat exchanger, as well as the influence of thermal interference between parallel sections of the heat exchanger pipe. It is necessary to investigate the influence on the heat removal from the soil mass of such factors as the thermal conductivity of the soil, the geometry of the location of the pipes of the ground heat exchanger.

Therefore, there is a need for an experimental study of thermal processes in the well of a ground heat exchanger when optimizing heat exchange characteristics as a result of electrohydroimpulse treatment and creating an energy-efficient technology for increasing heat transfer of heat exchanger wells.

The use of the electrohydraulic method for efficient drilling of rocky soil is an efficient and economically profitable way. Since this method, compared with mechanical, is characterized by lower energy consumption and greater drilling efficiency. Currently, systems with vertical ground heat exchangers are widely used. Therefore, research on the development of an electrohydraulic installation and a working chamber for drilling is relevant.

2. Literature review and problem statement

Drilling of soft rocks is carried out by mechanical method, and electrohydraulic method is used for effective drilling of rocky soil. This method, in comparison with mechanical, is characterized by lower energy consumption and greater drilling efficiency [1]. In this paper, the process is mainly described not in real time, but in the form of computer modeling. And the design of the monitoring system for the JD15 electrohydraulic control drilling rig and the functional requirements for various parts.

The work [2] provides optimal parameters and their limit values, in particular, the shape of the cut, the angles of the cut, the possibility of changing the design of drills and their constructive application. Milling cutters working on hard rocks, compared to block milling cutters for soft rocks, using a solid or discrete cutting line. The possibilities of using this approach are confirmed by the tool designs proposed by the authors, as well as common combined bits. The development of drilling tools with adaptable parameters allows to create a new high-performance cutting drilling tool. However, the variable parameters of the drilling cutting tool proposed by the authors of the works cannot be fully used to create highly efficient cutting bits that provide automatic installation of rational geometric parameters of the cutting blades during the drilling of a well in rocks alternating in strength, since the conditions proposed by the authors are created from the judgments obtained.

The purpose and capabilities of the modules of a special software package integrated into a single complex of network automated laboratories for mathematical modeling of the organizational and economic component of the information vector of the educational process are studied [3]. The authors in this paper only recommend methods for evaluating the procedures for developing an organizational and economic mechanism for project management. More detailed information is not offered.

In this article [4], the concept of mathematical modeling, the classification of models and the application of mathematical modeling methods for a physical process were studied. The authors in this paper gave only a complete concept of the term «mathematical modeling». The article discusses the types and methods of modeling, but does not describe their application in processes.

The article [5] discusses information theories for the development of optimal models. The new concept of introduced uncertainty chosen by the authors can be widely used and universal. The authors gave examples of the proposed approach in relation to the Heisenberg uncertainty relation, heat and mass transfer equations and measurements of the fine structure constant. In the article, the authors proposed a universal metric of the uncertainty value of mathematical models of micro- and macrophysics using the application of information theory. Thus, the problem of uncertainty that exists before the start of an experiment or computer simulation and arises as a result of a limited number of variables recorded in a mathematical model is usually ignored in measurement theory. But the proposed model does not fully disclose the mathematical model of drilling.

The study [6] concerns mathematical modeling of the process of grinding the soil during drilling and removal of solid particles (sludge) from the surface using drilling mud. The process of rock destruction is explained by mathematical modeling. In most cases, a system of nonlinear differential equations is obtained, from which new relations of equations are obtained. The SIMPLE algorithm is used for this. In this article, the authors described the process of rock destruction using the mathematical theory of fragmentation, which does not reveal the entire process of destruction. The destruction process consists of systems of nonlinear partial differential equations, for which a new closing relation is derived. The authors also showed how to solve these equations.

The research [7] examines the economic problems of water consumption for existing thermal power plants. In the future, the power plant could reduce water consumption by investing in efficiency improvements. The paper considers the needs of thermal power plants in cooling water. The specific numerical values of water consumption in the districts are given, but the ways to solve them are not given.

Work [8] shows improved electrode tips in a high-voltage electric pulse drilling (EPD) system. The authors obtained three-dimensional (3D) graphs of the reconstruction of broken granite, and drilling with a diameter of 60 mm was carried out in granite and red sandstone. Comparative data were obtained before and after the improvement of the electrode tips. The advantages of electro hydraulic drilling are shown. The authors investigated electrohydraulic and giant drilling rigs that are commonly used in underground coal mines and tunneling tunnels for drilling blast wells and installing anchorages. The authors have shown that the area of the well, the impact energy (blowdown), the number of piston strokes per minute inside the drilling rig and some properties of the rock, such as uniaxial compression strength (UCS) and the drilling speed index (DRI), affect drilling performance. But these drilling rigs are very labor-intensive and energy-intensive. The authors did not provide ways to solve them.

In [9], combinations of physical and mathematical models of the impact and penetration processes of cylindrical rods are presented, and a computational and experimental method for describing the deformation and specific properties of the Earth's environment with significant pressure changes is developed. The book presents methods for identifying parameters of mathematical models of dynamic deformation of soil media in a wide range of pressure changes and deformation rates, as well as an experimental and theoretical study of non-stationary processes of high-speed impact and inclined penetration of bodies of rotation into compressible porous media using accurate solutions and data from numerical and physical experiments. But the authors did not take into account the mathematical modeling of these processes.

The article [10] describes the uncertainty of the lateral position of the well during magnetic/gyroscopic measurements during drilling (MWD) can often exceed the requirements for collision prevention, for optimal placement of the laying wells between existing producers or for hitting targets with a limited geological extent. The uncertainty of location determination can be significantly reduced by implementing high-precision localization of the drill bit using passive seismic data. Consequently, not only drilling risks can be reduced, but also optimal drainage of the reservoir can be ensured. The article describes the whole process of drilling wells. Examples of the position of wells and their types are also given. But the authors do not give the exact type of drills that can be used to drill these wells. Also, the mathematical model of drilling rigs was not described.

In connection with the above, it is necessary to propose the experimental installation for drilling wells using electrohydroimpulse technology.

3. The aim and objectives of the study

The aim of the study is to determination the thermal modes of heat exchangers of a heat pump installation located in the bowels of the earth using electrohydroimpulse technology. This will make it possible to determine optimal energy of destruction of natural stones is determined depending on their thickness and hardness.

To achieve this aim, the following objectives are accomplished:

– to develop and create an electrohydraulic installation and a working chamber for drilling;

– to develop and create an experimental stand for modeling heat transfer processes in heat sink elements of a heat pump.

4. Materials and methods

Engineering-geological zoning of the territory of the Karaganda region belongs to the denudation-erosion upland area. According to the complexes, there is granite-diorite, porphyrite-tuff-porphyry, quartzite-slate-gneiss, sandstone-argillite-porphyrite, sandstone-slate-limestone, loamy-crushed stone characterizing the corresponding areas of a certain formation. Therefore, the object of the study is solid rocks in the form of natural stones with an average thickness from 53 mm to 78 mm.

The main hypothesis of the study is that the propagation of the pulse pressure created by electric discharges in an inhomogeneous fluid during well drilling is inhomogeneous. Also, in the bowels of the earth, an underwater electric explosion makes it possible to increase the diameter of wells where there are sands with frequent interlayers of clays and in sands with layers of gravel and pebbles of the second above-floodplain terrace at a depth of 5–10 m.

As is possible to assume, the use of the proposed device with a paraboloid reflector focusing an electrohydraulic shock directed towards the destructive material allows not only to reduce energy losses and also to increase patency in layered rocky soil.

To simplify the results of the experiment, let's use the program Temp.Keeper. With its help, it is possible to see the data received from the temperature sensors inside the well in real time. The Temp.Keeper program is used around the clock to monitor and control humidity and temperature of various environments or objects on which sensors are installed. In addition, with the help of thermal sensors during operation, it is possible to control the temperature in the ground of the well. In our region, the ambient temperature drops to –35 °C in winter, and to +40 °C in summer.

As it is known, natural stones are called solid pieces of rocks that appeared as a result of crushing. In their structure, texture and composition, they differ greatly from each other, and therefore there are extremely many types of them: marble, granite, limestone, as well as shales, shell rock, basalt. Photos of natural stones before processing are shown in Fig. 1.

Fig. 1. Photos of stones before processing (53÷78 mm)

Processed natural stones with an intermediate thickness from 53 mm to 78 mm were used in the experiments. The experiment was conducted as follows. An electro hydraulic drill was installed on the surface of the stone in a water tank. After the installation was started, the number of discharges preceding the destruction process was determined.

In the course of experimental studies, an electro hydraulic installation and a working chamber for drilling were assembled at the laboratory experimental site (Fig. 2).

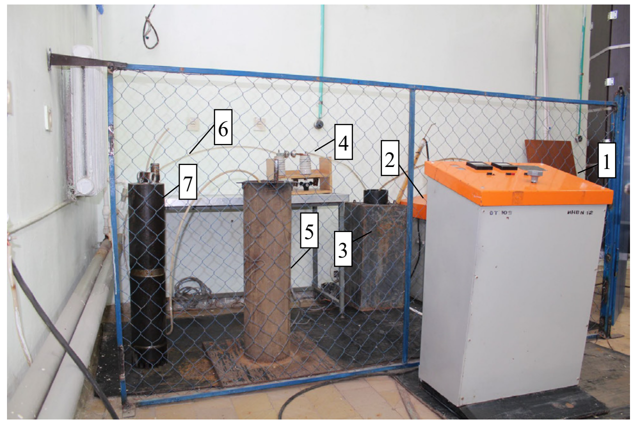

Fig. 2. The appearance of an electrohydraulic installation and an electrohydraulic drill

The installation consists of a control panel 1, a transformer 2, a pulse capacitor 3, a spark gap 4, a small electrohydraulic drill, d=110 mm, installed in the working section 5, an electrode cable 6 and a big drill 7, d=160 mm. The bench model was developed to determine the physical capabilities of an electrohydraulic drill. The operation of an electric drill is described in [10].

5. Results of electrohydraulic drilling and process modeling

5. 1. Development of an electro hydraulic installation and a working chamber for drilling

The use of the proposed device with a paraboloid reflector focusing an electrohydraulic shock directed towards the destructive material allows to reduce energy losses and increase patency in stony ground.

Fig. 3 shows the installation of suspended equipment manufactured at the laboratory site during equipment testing. Fig. 4 shows a sample of an electrohydraulic drill used for testing.

Fig. 3. Installation of suspended Equipment

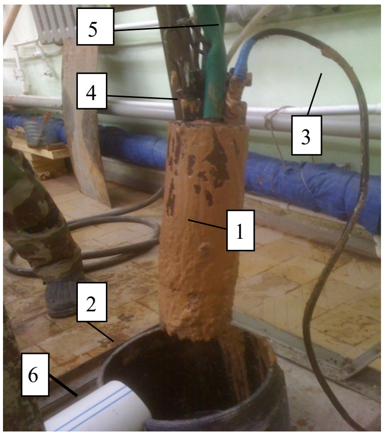

Fig. 4. Electrohydraulic drill: 1 — electrohydraulic drill; 2 — borehole; 3 — positive cable electrode; 4 — water supply hose; 5 — negative cable electrode; 6 — drain pipe

Based on data-based studies, the limits of the electrophysical parameters of the approach were established, at which the concentrated destruction of hard rocks – the main stones – begins. The effective amount of energy for the destruction of stones with a thickness of 53 mm is 900 J (Table 1). For stones with a thickness of 78 mm, there should be 2600 J. If to increase the energy of the discharges to 1837 J, the process of complete destruction of the stones is underway. This fact indicates the presence of certain optimal values of the electric discharge energy.

Table 1

Results of the experimental study

The set values			Results of the experiment		
U_O, 10^3 V	C, 10^{-6} μF	h, m	n	l_p, m	W, 10^3 J
30	2	0.053÷0.061	100÷250	0.007÷0.015	900
36	2	0.062÷0.069	100÷250	0.007÷0.015	1296
40	2	0.070÷0.074	100÷250	0.007÷0.015	1600
46	2	0.071÷0.076	100÷250	0.007÷0.015	2116
51	2	0.072÷0.078	100÷250	0.007÷0.015	2600

At the corresponding time, the release power during the working period varied W=900÷2600 J. Processed natural stones with an intermediate thickness from 53 mm to 78 mm were used in the experiments. After the installation was started, the number of discharges preceding the destruction process was determined. As a result of the experimental study, the following results were obtained (Table 1).

Fig. 5 an electric drill for crushing soft rocks. Fig. 5, *a* shows the appearance of the drilling rig, and Fig. 5, *b* shows the drilling rig during operation. When the drill collided with hard rocks, an electrohydraulic drill was connected. The operation of an electrohydraulic drill is based on the fact that when a given voltage is reached, the spark gap breaks through and all the energy accumulated in the capacitor is transferred via an electrode cable to the operating interval of the electrohydraulic drill. A pulsed electric discharge occurs in the liquid, which is a source of powerful mechanical shock waves, which, reflecting from the paraboloid surface of the inner part of the drill, focus on the treated rock, thereby destroying it into small pieces. Drilling of the earth was carried out to install thermoelectrodes in the bowels of the earth (Fig. 6) to determine the temperature of the earth at different depths.

a *b*

Fig. 5. Small drilling rig

a

b

Fig. 6. Connecting wells in a well

The cable electrode on the installation is flexible, due to this it is possible to obtain the results of the electrophysical parameters of the approach, at which the concentrated destruction of hard rocks – the main stones begins. The initial well drilling tests were carried out in the laboratory. One of the advantages of the laboratory is that in tight circumstances it makes it possible to drill the ground up to 25 m. A further increase in depth over 30 m, reduces the power of the installation.

In particular, studies were conducted to determine the best average value of the electrohydraulic method of installation, tests were conducted to identify the discharge power for the effectiveness of the electric discharge approach to the destruction of normal minerals. The values of the maximum permissible unit emission power are calculated based on the classification and prevalence of common minerals. Dependencies that indicate the beginning of the process of destruction of rocks of different widths, depending on the volume and strength of the ejection. The study conducted on the basis of the data obtained allowed to achieve higher drilling rates compared to conventional installations. Destruction is not supported, does not require characteristic requirements for electrodes on the surface, and therefore the resistance of worn electrodes when receiving electrohydraulic impulses is small. The electrode line, which is an expensive material, is subject to wear.

The objects of electrohydraulic processing were hard rocks in the form of natural stones. Natural stone is a material of natural origin, having a diverse structure formed as a result of crushing solid pieces of rocks. In the experiment, natural stones were used, the hardness of which is 5–6 % on the Mohs scale.

After drilling a well with a depth of 25 m, a U-shaped heat exchanger was installed. Fig. 6, *a* shows the supply and return of the pipe. Fig. 6, *b* shows connecting pipes to 5 wells. Antifreeze flows inside the pipes. Thermal sensors were installed on the outer surfaces of the pipes, with the help of which the earth temperature was determined at different depths of the well. The data was obtained using the program Temp.Keeper.

5. 2. The results of modeling the temperature conditions of the heat pump radiator

To determine the effect of the coolant velocity on the temperature regime for the heatsink of the heat pump, let's obtain full-scale results from wells where thermal sensors are installed. These results are shown in Fig. 7–10.

The data obtained is stored in a computer database using the Temp.Keeper computer program, which allows to track the temperature in wells. A full-scale test of a heat pump unit powered by an external circuit located at the landfill was carried out. The average temperature in the wells is 9 °C, in the external circuit 52 °C. Tests have shown stable, stable operation of the heat pump unit.

Fig. 7 shows the test tests of the pump and the heat pump unit after preparation and startup.

This installation has been operating in real time since 2016. During the heating season from October to April. This Fig. 7, 8 shows the results of 2016. As the data shows, after turning on the installation, it takes time before setting the mode. After the first stop, the installation was started again. From 2016 to the present day, the installation is in working condition. As it was shown in the graphs, some sensors have failed, but the main ones are in working condition and continuously shows temperature conditions.

On the basis of the prepared complex, the working thermal parameters of the heat pump installation are investigated depending on the results of electrohydroimpulse action, the temperature of the medium and the geometry of the system.

The developed system allows temperature measurements at various points of the heat exchange circuit, including the entry and exit points of each heat exchanger in the central well. The study of the operating thermal parameters of a heat pump installation in a soil massif at different ambient temperatures, taking into account the different treatment of wells with shock waves and different geometries of installed heat exchangers. The obtained data is stored in a computer database using the Temp.Keeper computer program, which allows to monitor the temperature in wells in a given configuration both point-by-point and in dynamics with real-time data processing.

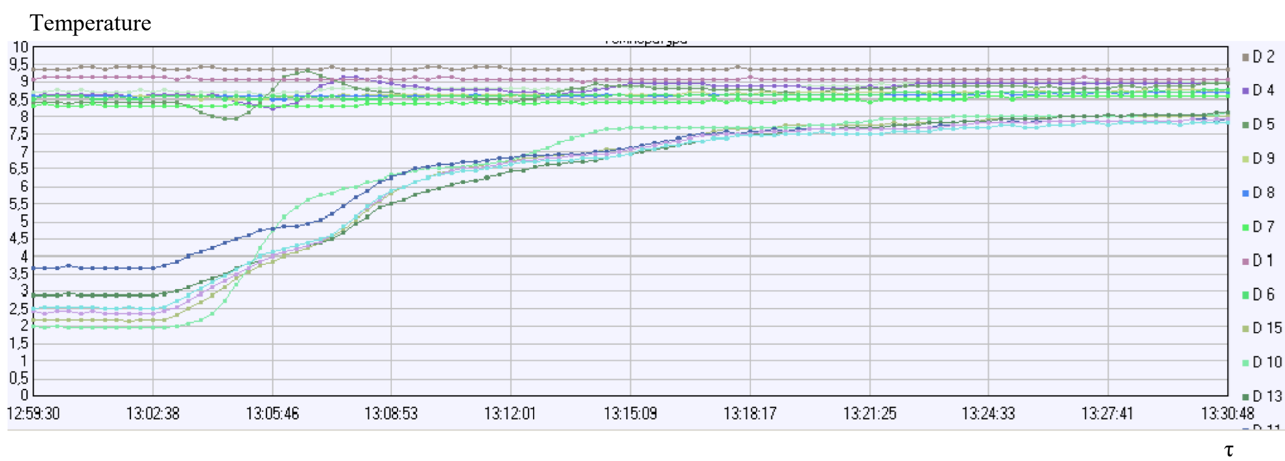

Fig. 7. Temperature change indicators in the Temp.Keeper program from 08.11.2016

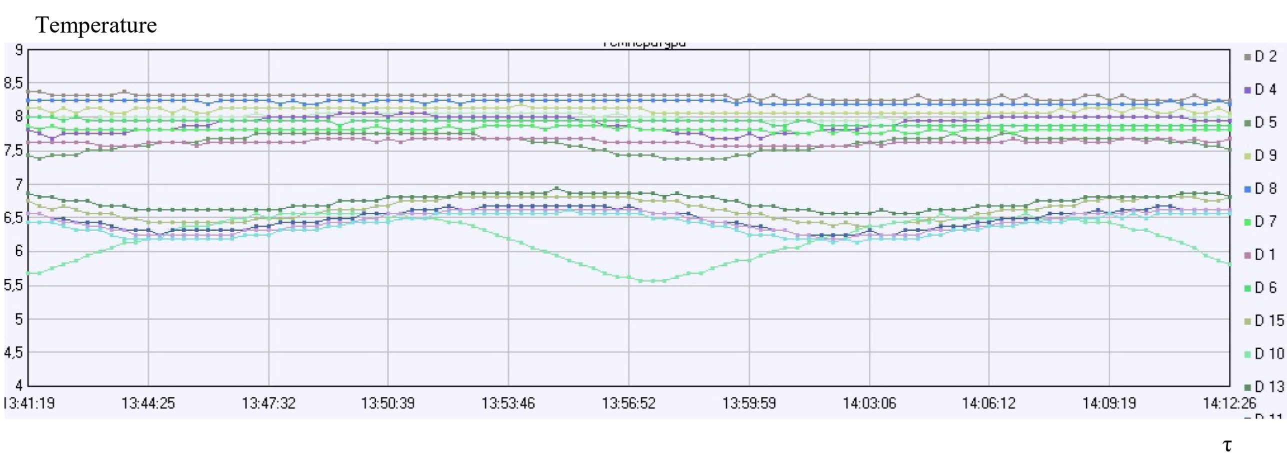

Fig. 8. Temperature change indicators in the Temp.Keeper program from 17.11.2016

Temperature

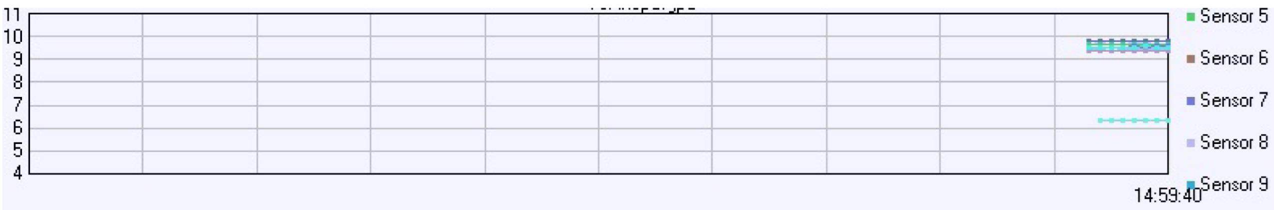

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Fig. 9. Temperature change indicators in the Temp.Keeper program from 14.03.2023

Temperature

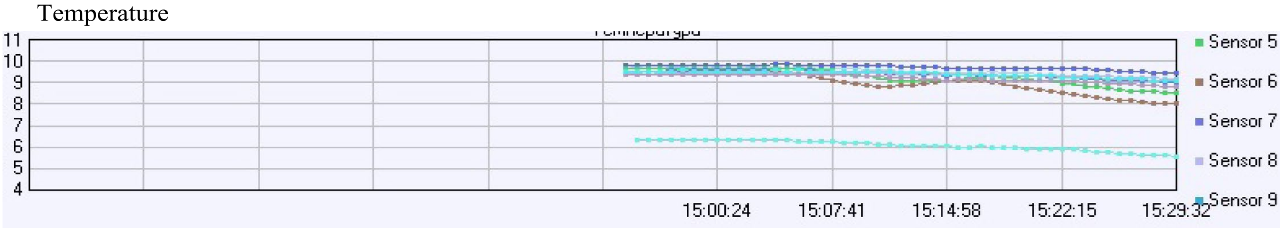

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Fig. 10. Temperature change indicators in the Temp.Keeper program from 14.03.2023

To obtain temperature change indicators, temperature measuring systems-temperature sensors (Dallas Semiconductor c DS18B20) were designed, which are fixed at the inlet and outlet to the well of the heat exchange pipeline. The data obtained is stored in a computer database using the Temp Keeper computer program, which allows to track the temperature in wells. As can be seen in Fig. 7, the highest temperature was observed at depths of 17 m and 12 m. The temperature measurement interval is 55 min.

The systematization of the array of information received with the indication of the measurement time and the analysis of the processes under consideration was carried out. Fig. 9 shows a small fragment of graphical dependencies and tabular data for a time interval of 30 minutes. This study lasted for 3.5 hours at an ambient temperature of –28 degrees Celsius. The thermal operating parameters of the heat pump installation in the autumn, winter and spring periods for different ambient temperatures with different geometry of the heat exchange circuit and soil characteristics are investigated. Fig. 9, 10 show a small fragment of graphical dependencies and tabular data obtained on 14.03.2023.

As can be seen from the graph, the installed sensors in the depths of the earth show a temperature in the range of 9.75–9.81 °C. And sensors on the earth's surfaces show a temperature of 9.5 °C.

6. Discussion of the results obtained in determining the best average value of the electrohydraulic installation method

The technological solution is achieved due to the fact that the device for drilling wells for installing heat exchangers contains a pulse current generator with a power source and associated cables-electrodes of an electrohydraulic drill, of which it has a barren core. In an electric explosion, the energy of the shock wave can propagate isotropically in all directions, and with the help of a paraboloid reflector, it is possible to concentrate in the preferred direction. Their experience shows that while maintaining paraboloid reflectors, it is possible to imagine a cumulative amplification of the shock wave power. The greatest efficiency was recorded when the cable electro deck was placed between the focal point of the paraboloid reflector and the double focal point. For drilling wells by the electrohydraulic method and can find application in drilling shafts and wells, destruction and crushing of rocks.

The developed system allows temperature measurements at various points of the heat exchange circuit, including the entry and exit points of each heat exchanger in the central well.

In [1, 2], only drilling of soft rocks is considered. Drilling is carried out by a mechanical method, and in our work an electrohydraulic method is used for effective drilling of rocky soil.

Improved electrode tips are shown in [8], but this does not give the desired result. One of the advantages of our drill is that the inner part of the drill is made in the form of a paraboloid made of steel, which provides, due to the cumulative effect, an increase in the strength of the shock wave. During an electric explosion, the energy of the shock wave propagates in all directions, isotropically, and with the help of a paraboloid reflector, it can be concentrated in one preferred direction. This makes it possible to save energy and cut through the stone at one point.

In other articles [10, 11], the values of their effective explosion energy were studied and determined depending on the thickness of stones less than 60 mm. This article discusses the parameters of the destruction of stones with a thickness of over 60 mm. To do this, let's assemble a more powerful installation with a voltage exceeding 15 kV. The temperature of the earth revealed in the work has not changed over the past 5 years.

The peculiarity of this method in comparison with other methods is that no special land plot is required for installation. For example, this installation can be installed under a house or building and continue to work. And the disadvantage is that the water must flow continuously. When crushing hard stones, drilling rigs often fail.

In addition, the dependence of temperature on time at coolant velocities of 0.2÷0.4 m/s was considered. The study showed that a significant decrease in temperature in the well and at the outlet was observed at a coolant velocity of 0.35 m/s for one hour.

With the help of the installations shown in Fig. 4, 5, optimal parameters of the destruction of hard rocks were obtained. The effective amount of energy for the destruction of 53 mm thick stones was 900 joules. For stones with a thickness of 78 mm, there should be 2600 j. If to increase the energy of the discharges to 1837 J, then the process of complete destruction of the stones is underway. The test results are also shown in Table 1.

Let's also investigate the temperature conditions of the soil. The data obtained is stored in a computer database using a computer program Temp. Keeper, which allows to monitor the temperature in wells. To do this, thermoelectrodes were installed in different depths of the earth. The data obtained in 2016 are reflected in Fig. 7, 8. As can be seen in Fig. 8, the highest temperature was observed at depths of 17 m and 12 m. The temperature measurement interval is 55 min.

Fig. 9, 10 show the temperature regimes obtained in 2023. Temp.Keeper, which allows to monitor the temperature in wells. As can be seen from the graph, sensors installed in the bowels of the earth show a temperature in the range of 9.75–9.81 °C. And sensors on the earth's surface show a temperature of 9.5 °C.

In comparison with other works, we have assembled an experimental setup. Based on data-based studies, the limits of the electrophysical parameters of the approach were established, at which the concentrated destruction of hard rocks – the main stones – begins. The ability to obtain high-precision temperature and flow measurements, as well as the proper supply of constant thermal energy to the well are the main requirements for the evaluation of the experimental installation. temperature sensors are installed in the middle of the *U*-shaped heat exchanger and in a vertical form on the surface of the pipe, which monitor temperature indicators. Using the Temp.Keeper program recorded data received from temperature sensors inside the well. With this program, it is visually possible to monitor the changes that are taking place, as well as check the presence of these parameters in the standard, warning with an audible signal, if necessary.

Thus, when the set voltage is reached, the spark gap is broken, and all the energy accumulated in the capacitor is transferred via an electrode cable to the operating interval of the electrohydraulic crusher. A pulsed electric discharge occurs in the liquid, which is the standard of effective automatic shock waves, which, reflecting from the drill bit, focus on the cleaned rock, thereby destroying it into small pieces.

However, additional financial investments are required to create this installation and to fully implement it. Also, specialists are needed to manufacture a high-voltage step-up transformer. In addition, it must be borne in mind that the electrode system used, which is an expensive material, is susceptible to wear.

The use of this installation makes it possible to prepare wells in the basement and in the basement floors for further installation of heat exchange elements of heat pumps.

7. Conclusions

1. An electrohydraulic installation and a working chamber for drilling were developed and installed for the study. During the experiment, the most optimal energy of 900 J for the destruction of stones with a thickness of 53 mm was established, and for stones with a thickness of 78 mm it is equal to 2600 J. With an increase in the discharge energy to 1837 J, a complete destruction of the stones is observed.

2. With the help of the installation, the results were obtained: the highest temperature was set at a depth of more than 17 meters. It was 9.8 °C. And on the surface less than 9.5 °C.

Conflict of interest

The authors declare that there is no conflict of interest regarding this research, including financial, personal, authorship or other nature that could affect the research and its results presented in this article.

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Data availability

Data will be provided upon reasonable request.

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