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UDC 622.143:628.1

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SCIENTIFIC AND TECHNOLOGICAL FOUNDATIONS FOR GROUNDWATER EXTRACTION BY THE INJECTION-FORCED SELF-DISCHARGE METHOD

The problem of developing underground water deposits is particularly relevant at the moment. The existing method of opening aquifers by drilling vertical wells is ineffective in terms of water yield in relation to the amount of drilling activity, material and labor costs.

A system for opening and extracting underground water by the injection-forced self-discharge method is proposed, based on the use of internal energy of aquifers and the physical principles of water withdrawal (injection) and lifting to a height (hyd-ram).

Structurally, the system consists of an injection and a water-lifting well connected by a smooth bend at depth and oriented towards the attitude of aquifers.

The system is equipped with a cascade of a hydrojet device designed to implement the effect of injection and a hyd-ram, as well as a water return tank.

The initial hydrogeological prerequisites for extracting underground water by the injection-forced self-discharge method were established, and the conditions and means of creating a system of communicating wells were determined.

The design parameters of the hydro-jet device cascade and their purpose were specified.

The system technical capabilities test was carried out on a test-setup designed in accordance with the research objectives and the physical principles of modeling hydraulic phenomena.

A series of experiments recorded the dependence of the injection coefficient on the gravitational water yield coefficient at different working water flow rates.

Information is given about the advantages of the proposed system for extracting underground water by the injection-forced self-discharge method in comparison with the traditional method of exploration and development of underground water deposits.

Keywords: *underground water, drilling, wells, aquifers, injection, hyd-ram, hydrojet, self-discharge*
DOI: *10.17580/em.2021.02.06*

Introduction

Traditional for all types of groundwater deposits, the method of opening aquifers by drilling vertical wells is obsolete. The disadvantages are a significant amount of well drilling in waste rocks, a limited area of opening aquifers in relation to the value of their thickness, low water yield, the need to use energy-consuming deep pumps and airlifts, laborious to maintain and repair, to extract water.

There was a need for a radical restructuring of the system for the development of groundwater deposits on a new ideological basis, where the efficiency indicator is the ratio of the volume of extracted water to the physical volume of well drilling.

The main idea is to achieve a forced groundwater self-discharge by using the internal energy of aquifers in combination with the physical principles of water withdrawal (injection) and lifting to a height (hyd-ram).

The idea of the injection-forced groundwater self-discharge method was taken from the practice of drilling hydrogeological wells, when during experimental pumping, water pumped into one of the wells came out of another well at a distance of more than a hundred meters at a much higher rate.

On this basis, and taking into account the direction of movement of pressure water in aquifers, to implement the idea, a system was formed, consisting of an injection and a water-lifting well, obliquely oriented in the reverse direction with a smooth butt joint at depth. Taking into account the location intervals and attitudes of aquifers, wells are equipped with filter columns and a cascade of a hydrojet device designed to enhance the effect of injection (suction) of water from aquifers and lifting to a height by the force of a hyd-ram.

The system of communicating wells and the cascade of the hydrojet device together form an integral line of water flow in the direction of aquifers – to the surface of the earth.

Tasks

1. The determination of hydrogeological prerequisites for groundwater extraction by the injection-forced self-discharge method.
2. The choice of method, means and technology for the construction of a system of communicating wells, the determination of the composition and design purpose of the hydrojet device cascade elements.
3. The substantiation of the idea and technical capabilities of the injection-forced groundwater self-discharge method.

Research methods

From an analytical review of geological materials on the origin and conditions of groundwater deposit positions, it follows that for the implementation of the injection-forced self-discharge method, artesian high-pressure and pressure waters located in aquifers between impermeable horizons are of greatest interest.

In addition to the bounded aquifers attitude, the direction of water movement in them, when designing a system of communicating wells, it is also important to take into account the aquifer water yield coefficient. The processes of groundwater yield by rocks are divided into gravitational and elastic. In practical calculations, gravitational water yield prevails, which is understood as the ability of rocks to give groundwater contained in them by means of free passage under the influence of gravity. The quantitative value of the gravitational water yield is the gravitational water yield coefficient:

$\mu = V_w/V$,

where V_w – effluent water volume, V – drained rock volume.

The effectiveness of this scheme in relation to water yield also depends on the method and means of well drilling, focused on ensuring the stability of the walls, preventing the clogging of aquifers and the accuracy of their butt joint with a smooth bend.

Unstable aquifers are prone to collapse when exposed to hydrodynamic, shock loads from the rotary drill stem and the turbulent mode of movement of the upward fluid flow with cuttings.

The clogging of aquifers occurs as a result of cuttings and the dispersion phase of clay mud penetrating into the interstices and cracks. The accumulation of cuttings is typical for long-wall well-drilling.

The solution to the problems of opening aquifers by means of a system of communicating wells is the transition to another method of drilling wells with core sampling without the rotation of the drill stem, using the hydrojet effect of rock destruction at low values of axial load on the bottom-hole and the rock-breaking tool rotation frequency.

To do this, a bottom-hole assembly was formed consisting of: a hydraulic machine, small in length, with low consumption of working fluid, a core barrel with non-rotating centralizers and a floating core receiver, thin-walled diamond bits with a separate system of flushing ports and a hydrojet effect of rock destruction [1, 2].

When drilling in hard and very hard rocks, bits are equipped with impregnated diamonds of medium hardness and, below, diamond-carbide inserts of the PDC type.

As a flushing fluid, polymer-based clay-free completion fluids are effective.

Prototypes of the bottom-hole assembly have passed production tests at the poly-metal deposits of Central Kazakhstan when drilling slanted wells at an angle of 70° under comparable conditions for the use of assemblies with removable HQ core receivers. According to the test results, measurements of the angles of well deviation with a length of 322 m showed that non-rotating centralizers with a diameter close to the diameter of a diamond bit ensured the preservation of a given direction of wells without deviation.

The advantage of a thin-walled diamond bit is a smaller bottom-hole destruction area, therefore, a smaller amount of cuttings, improved conditions for matrix cooling and cuttings removal, an increased core diameter that is more resistant to destruction.

Table 1 below shows the comparative indicators of HQ assemblies and a bottom-hole assembly.

The efficiency of groundwater extraction by the injection-forced self-discharge method is also determined by the design parameters of the hydrojet device.

In [3], a method for calculating high-performance ejectors was developed, where the optimal ratio of the longitudinal dimensions of the internal section was established, which ensures the ejection coefficient effective value.

It has been experimentally proven that with an increase in the salinity of the working fluid, the head-energy characteristics of the ejectors improve. This indicates the advantage of using the injection effect during the opening and extraction of mineralized groundwater [4].

Table 1. HQ assemblies and a bottom-hole assembly comparative indicators

Type of equipment	Drilling diameter, mm	Core diameter, mm	Category of rocks by drillability	Mining metreage per run, m	Well-drilling regimes		
					Axial load, kgf	Rotation frequency, rpm^{-1}	Consumption of working fluid, l/min
HQ assemblies	95.6	63	9–10	1.6–2.5 (cycle)	1200–1500	400–600	60–80
A bottom-hole assembly	95.6	69	9–10	3.8–5.1	600–700	200–300	90–110

To reduce the economic costs of the injector nozzle of sprayers, water-air ejectors have been developed with the possibility of saturating the working solution with air bubbles. There is evidence of a reduction in the consumption of the working fluid up to 18–25% compared with standard spraying methods [5].

In order to increase the ejector efficiency, a design of the agitating device in the form of a rotating nozzle was proposed, which achieves the maximum increase in efficiency by 37% [6].

The study [7] discusses the directions of future scientific research to solve the problems of the «multidimensional ejector» in various fields of human activity.

Numerous studies have been published detailing various hydrodynamic and mass-exchange aspects of gas induction in ejectors. The effects of turbulence and its influence on the jet dynamics and the rate of gas induction in the ejector were studied [8].

Hyd-rams are a self-adjusting self-oscillating device that converts the kinetic energy of a part of the water entering it into the potential energy of excess pressure due to a periodically repeated hydro-shock. The term «hydro-shock» refers to both an increase and a decrease in pressure [9].

The hyd-ram uses the energy of falling water, so for its operation it is necessary to have some level difference between the drainage area and the hyd-ram, starting from 0.2 m and above.

Hyd-rams can be installed in low-head water developments. There are hyd-ram designs by foreign firms, the characteristics study of which were carried out at a feed pump of 3 m.

Researchers involved in the development of a hyd-ram came to the conclusion that the optimal length of the injection pipe should be at least 10 m. This is explained by the fact that for a hydro-shock capable of lifting the fluid flow to a sufficient height, there must be an appropriate flow mass [10].

The works [11-13] present the principles of designing a hyd-ram, information about the optimal design, the results of the hyd-ram pumping system performance analysis, the effect of water pressure head on the hyd-ram performance, the design and hydraulic characteristics of the new hyd-ram.

The justifiability of the idea of extracting groundwater by the injection-forced self-discharge method and the hydrojet device cascade technological capabilities were tested on a test-setup (see figure), designed in accordance with the research objectives, the physical principles of modeling hydraulic phenomena and with standard filter column dimensions.

The basis for the development of design and technological documentation of the test-setup was the calculation results of the hydrojet device cascade parameters.

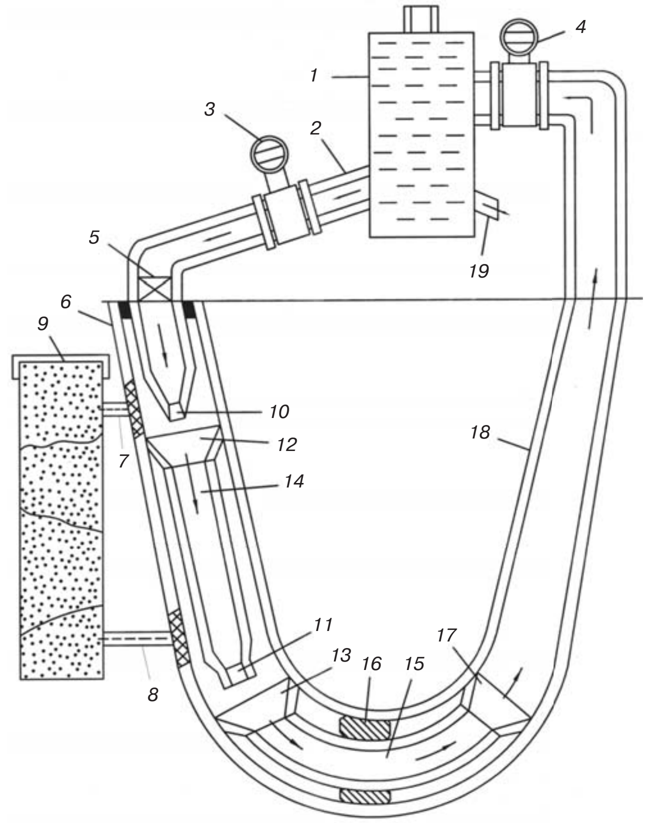
The defining parameter of the hydrojet device cascade is the area ratio coefficient m:

$m = f_{cm}/f_{c}$,

where f_{cm} – mixing chamber area, f_{c} – nozzle (nose-piece) area.

The following are calculated in succession: the nozzle exit diameter and length, the mixing chamber diameter and length, the injection coefficients representing the ratio of the injected flow to the working one, the receiving chamber inlet diameter and length, the diffuser bottom diameter, length and exit section. The test-setup also included a tank with alternately filled rocks with known values of the gravitational water yield coefficients.

Water was pumped into the tank and replenished under the influence of gravity and according to the estimated aquafer pressure.



Scheme of the test-setup for the reproduction of the injection-forced groundwater self-discharge:
1 – tank; *2* – pressure pipeline; *3* and *4* – flow meters; *5* – valve; *6* – downpipe; *7* and *8* – side pipes; *9* – tank with water-bearing rocks; *10* and *11* – nozzle; *12* and *13* – receiving chambers; *14* and *15* – mixing chambers; *16* – centralizer; *17* – diffuser; *18* – ascending (water-lifting) pipe; *19* – branch pipe

The test-setup provides for the possibility of changing the inclination angle of the downpipe and ascending pipe, the radius of the inter-pipe smooth bend, and controlling the working flow rate. At the same time, the tie-in entries of the side pipes *7* and *8* into the downpipe *6* are equipped with a mesh wrap (filter), which eliminates the possibility of various mechanical impurities coming from the tank *9* into the hydrojet device cascade, which may lead to clogging the holes of the injection nozzles *10* and *11*, followed by a system stoppage.

According to the recommendations [2], filters are installed at a distance of 0.5–0.6 m above and below the tie-in entries of the side pipes *7* and *8* into the downpipe *6*.

When the adjustable valve *5* is opened and the system begins to work, the working water flow goes from the tank *1* through the pressure pipeline *2*, where the flow meter *3* is installed, through the nozzle *10* enters the receiving chamber *12*, carrying the water mass through the side pipe *7* from the tank *9* filled with water-bearing rocks. The carried flow through the downpipe *6* is called injected, where the kinetic energy of the working flow is partially transferred to the injected one. Through the receiving chamber *12*, the working and injected flows enter the mixing chamber *14*, where their velocities are equalized, which is usually accompanied by an increase in pressure. From the mixing chamber *14*, the flow goes through the nozzle *11* into the receiving chamber *13*, taking up water from the lower part of the tank *9* through the side pipe *8*. The flow velocities of the working and injected water in the mixing chamber *15* in the centralizer *16* are again equalized, with an increase in flow pressure. From the mixing chamber *15*, the flow enters the diffuser *17*, where the kinetic energy of the moving fluid is converted into potential energy, as a result of which the pressure increases even higher.

Further, the flow through the conically narrowed body of the ascending pipe (water-lifting) *18* in the direction of water movement, through the flow meter *4* enters the tank *1*. Excess water is discarded through the branch pipe *19*.

The mixed flow pressure at the outlet of the diffuser *17* is higher than the injected flow pressure entering the receiving chamber *12*.

Increasing the injected flow pressure without the direct cost of mechanical energy is the main quality of the hydrojet device.

If there is an inter-pipe smooth bend in the test-setup, the water flow goes from the downpipe *6* to the ascending pipe *18* without loss of pressure and velocity, acquiring additional acceleration.

The technological capabilities of the hydrojet device cascade are evaluated in the velocity head and the injection coefficient K_u.

The velocity head of the water flow in the ascending pipe is determined by the formula:

$$H = P/\gamma + \vartheta^2/2q,$$

where P – water pressure at the outlet of the diffuser, γ – water volume weight, ϑ – the water flow velocity in the ascending pipe, q – acceleration of gravity.

The ratio of the injected water flow to the working one is called the injection coefficient:

$$K_u = Q_u/Q_p.$$

In this case, with a volumetric water discharge, the volume of injected water is determined by the difference in the readings of flow meters *3* and *4*.

The reproduction processes of groundwater extraction by the injection-forced self-discharge method at the test-setup took place in a self-oscillating operation mode, which was especially noticeable with an increase in the flow rate. This is due to the appearance of an incomplete hydroshock at the exit of the water flow from the nozzles *10* and *11*, a characteristic feature of which is a step-formed graph of the positive pressure wave.

Results and discussion

Experiments have proved the fundamental possibility of the idea of extracting groundwater by the injection-forced self-discharge method.

Table 2 shows the systematized results of experiments to determine the injection coefficient K_u (4) depending on the gravitational water yield coefficient at various working fluid flow rates.

From the given data, the dependence of the injection coefficients on the water yield coefficient and the working fluid flow rate is traced, which indicates a high potential of the hydrojet device cascade. At the same time, flow meters made it possible to control the flow rates of the working and mixed flows by setting the volumes of injected water in the circulation system.

Table 2. Dependence of the injection coefficient K_u on the gravitational water yield coefficient μ at various working water flow rates

Rocks	Gravitational water yield coefficient μ	Working flow rate, l/min		
		60	120	180
		Injection coefficient		
Fractured limestones	0.03–0.05	0.11	0.14	0.18
Quartz sandstones	0.12–0.15	0.23	0.31	0.37
Coarse-grained sandstones	0.2–0.25	0.4	0.48	0.55

According to laboratory studies, the proposed injection-forced groundwater self-discharge system can be effectively used in the opening and development of confined aquifers. The object of further research may be a detailed study of the interaction mechanism between an incomplete hydro-shock and an aquifer.

Presumably, if, with an incomplete hydro-shock, a wave of increased positive pressure in the interval from the nozzle 10 to the tank 1 will be focused on increasing the hyd-ram force, then the subsequent negative wave of reduced pressure reflected from the tank 1, reaching the nozzle 10, can contribute to the opening of interstices and cracks in rocks, hence increasing the water yield.

From the practice of developing groundwater deposits, it is known [2] that the hydro-impulse method of well development with alternating impact of shock waves on aquifers gives the maximum effect and allows, under certain conditions, not only to restore the permeability of the aquafer, but also artificially increase it.

The indisputable advantages of the system for extracting groundwater by the injection-forced self-discharge method compared to the traditional method of opening and developing aquifers are:

- groundwater extraction without the use of mechanical means and energy costs;
- in terms of water yield, the proposed system of communicating wells can replace 3-4 vertical wells drilled using conventional technology, with a significant reduction in drilling metreage, tubular products, material and labor costs;
- saving the bowels of the earth and the groundwater system, reducing ground infrastructure;
- solving the problems of the country's water security by transferring agriculture to irrigated farming, when water from wells drilled in the sown area will moisten the soil without loss during evaporation and return to the natural environment.

Conclusions

1. The main hydrogeological prerequisites for the implementation of groundwater extraction by the injection-forced self-discharge method are the attitude of aquifers, their thicknesses, hydrodynamic characteristics, the direction of water movement, and the rock water yield.

2. Based on the state of the mountain environment of groundwater deposits, the best way is to construct a forced water self-discharging system by drilling wells without rotating the drill stem with core sampling of increased diameter.

The design of the bottom-hole assembly was proposed, which eliminates the risk of negative factors characteristic of traditional drilling tools – the well walls stability loss, blockage of interstices and cracks in the aquifer with drilling cuttings, ensuring the safety of the given direction of the wells. With regard to the conditions for the implementation of the injection-forced groundwater self-discharge method, the constituent elements of the cascade of the hydrojet device built into the casing standards were established, the design parameters, the values of which are to be calculated, were indicated.

By reproducing the injection-forced groundwater self-discharge process at the test-setup, the feasibility of the proposed idea of developing aquifers by a system of communicating wells has been proved.

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