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IDENTIFYING THE OPERATING FEATURES OF A DEVICE FOR CREATING IMPLOSION IMPACT ON THE WATER BEARING FORMATION

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The object of the study reported in this paper is the parameters of a device for implosion impact on aquifers during well development.

The problem of increasing the productivity of aquifers was solved by removing colmatation products formed during the drilling process and restoring the natural permeability of the formations. This could ensure high production of wells and their long-term trouble-free operation. One of the most effective ways to develop wells is implosion impact. However, its use is hampered by the complexity of the structure of existing devices, the high cost of use, and the insufficient reliability of their operation. To overcome this, an original device for implosion impact on aquifers was designed and its operating parameters were determined.

A procedure has been devised for determining the maximum permissible sizes of intervals not filled with liquid under the conditions of preventing casing string collapse. The effect of these intervals on reducing the total weight of the casing string was investigated.

An optimal well structure was proposed for the conditions of the Tonirekshin field. The critical dimensions of empty intervals were calculated for all wall thicknesses of casing pipes included in the well design. It has been established that the amount of weight reduction of the casing string in the well due to the Archimedean force for field conditions is 43–47 %. Archimedean force increases with increasing pipe wall thickness. Reducing the weight of the casing string reduces the required winch power, allowing the use of lighter drilling rigs.

The procedure for preparing for repeated implosion impacts has been studied.

The studies performed and the recommendations presented will be effective when drilling and developing wells under the conditions of the Mangistau Peninsula, at the Tonirekshin field

Keywords: well development, implosion impact, casing string collapse, inlet valve, Tonirekshin field

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1. Introduction

After completing the drilling of water wells, it is necessary to carry out a set of works to ensure its productivity corresponding to the local capabilities of the aquifer. To this end, various well development methods are used, which are aimed at removing colmatation products formed during the drilling process and restoring the natural permeability of the formation. These methods are very diverse in terms of the principle of creation, the impact on the productive formation, the complexity of their organization, and have different effectiveness in different geological and technical conditions.

Selecting the optimal method for the conditions of a particular field is a complex and responsible task, the solution of which predetermines the productivity and efficiency of a production well over a long period of time.

The conditions for drilling water wells on the territory of the Mangistau Peninsula of the Republic of Kazakhstan were studied in [1, 2]. The productivity of previously drilled wells turned out to be too low. One of the reasons for this is the discrepancy between the well development methods used on the peninsula and the mining and geological conditions. It has been substantiated that the most effective in local conditions is the implosion impact on aquifers [3]. Scientific research into the operation of a device for providing implosion impacts on aquifers is important as it makes it possible to achieve maximum utilization of the capabilities of productive aquifers.

The results of these studies are of great practical importance because they will help meet the region's needs for drinking and domestic water supply.

2. Literature review and problem statement

The issue of well development is of great interest among specialists. This is explained by the importance of the problem and high economic efficiency if positive results are achieved.

Estimates of the permeability coefficient can be obtained by various approaches, mainly analytical and empirical. In [4], hydraulic conductivity was assessed based on the specific power of aquifers. The application of analytical methods requires verification of non-linear losses in the well due to turbulence and vertical flow associated with partial penetration. The empirical approach relates transmissivity values to specific transmissivity data measured in the same well. A new relationship is proposed for estimating hydraulic conductivity from specific power data in carbonate aquifers.

One of the most popular types of filters is gravel. An important task for the development of such wells is the correct design of the size of the gravel packing and the quality of the gravel material. New concepts for tapping the aquifer and designing the size of the gravel packing are presented in [5]. The authors performed a comparative analysis of grain size using bar graph and circle methods. The relationship between the grain size of the coating and the width of the gravel filter slot is indicated. It is concluded that the circular method is well suited for estimating the gap size, effective size, and uniformity coefficient compared to the grain size analysis curve. It should be noted that such well development methods are too passive and are effective only when used in thick aquifers with high reservoir properties. The conditions for drilling water wells on the territory of the Mangistau Peninsula do not make it possible to apply such measures only and require influencing the productive formation.

A method for dispersing and removing clogging deposits by creating a vibration effect of a powerful filtration flow of alternating direction in the filter cavity was proposed in [6]. This leads to multiple controlled explosions of the gas-air mixture, which allows this method to be used in a wide range of hydrogeological conditions, as well as in wells equipped with various types of filters. A mathematical model of elastic hydrodynamic oscillations in the aquifer has been constructed, which makes it possible to determine the magnitude of stresses at any point in the treatment of the near-filter zone of the well and, accordingly, to establish the required degree of destruction of the colmatant. It has been established that the power of the explosion determines the frequency of movement of the piston-projectile, which affects the vibration characteristics of the «filter-filter zone-aquifer» system. The cited work does not take into account the fact that the proposed method for removing clogging deposits affects not only the productive formation but also the casing string. However, its strength characteristics are a significant limiting factor that should be taken into account.

Work [7] analyzes the unsteady influx of groundwater to a real well (with shaft accumulation and skin effect), which completely penetrates the confined aquifer. A method for assessing well recovery at the initial stage of pumping tests is proposed. A new method for estimating the skin factor at the initial stage of pump testing is presented. This method can be used to estimate the skin factor when the well-known semi-log Cooper-Jacob method cannot be used because the second straight line is not reached on a semi-log plot of drawdown versus log time. A field example is presented to evaluate the restoration of a well in Veseli nad Luznice using a new correlation.

An assessment of well development using the method of air pulsation in bedrock aquifers is given in [8]. As a result of practical research, depression in test wells has been reduced and, accordingly, average specific flow rates and permeability coefficients have been increased. Additionally, this process examined changes in groundwater quality, as well as substances that cause deterioration of wells in primary aquifers. According to the results of the analysis of the quality of groundwater carried out during the surge and stepwise decline tests, there was no significant change in their quality before and after the surge. However, it was established that there was a supply of pollutants from the upper shallow strata, close to the surface.

The basic principles of restoring well productivity using acid treatments were studied in [9]. It has been shown that the disadvantage of acid solutions based on hydrochloric acid is the high reaction rate and the difficulty of getting the acid into the reservoir through the colmatation film. The mechanisms of decolmatation were modeled and studied, and an effective composition was developed for the restoration of deep wells, making it possible to reduce the corrosive effect. For specific conditions of depth and rock composition, it is necessary to devise an individual formulation of process fluids and technologies for treating the bottomhole formation zone and restoring well productivity.

The development of wells due to the cavitation effect on aquifers was studied in [10]. Sets of cavitation generators have been designed in combination with conventional conical hydrodynamic nozzles. Due to this, the pressure in the system is reduced, and the cleaning unit becomes lighter and more mobile. The nozzle geometry was designed and the development of cavitation in the flow was studied using a simulation method. It was shown that cavitation nozzles could effectively produce erosion at water depths to 300 m. Several sets of nozzle holders were then developed for cleaning water wells. The proposed technology makes it possible to develop a water well in 2–3 days without the use of heavy drilling equipment. The cost of the development process is 20–40 % of the cost of drilling a new well. It should be noted that the designed cavitation generators are complex since they include a tubing string separated by a packer, a wellhead seal, a compressor, and a surface piping for controlling the supply of compressed air. Therefore, their use under practical conditions is difficult and often does not give the expected results due to malfunctions that arise during their operation.

The theoretical foundations for controlling the cavitation-pulsating effect on rocks based on the theory of spectra are outlined in [11]. The energy distribution of cavitation-pulsating action on a rock mass has been studied. Experimental studies of the operation of a hydrodynamic pulsator were carried out and a calculation method for optimizing the cavitation-pulsating effect on rocks was devised. It should be noted that these experimental studies were carried out in a narrow range of initial parameters. The methodology devised considers the optimization process only from the point of view of the impact on the formation and does not take into account the limitations imposed by the strength characteristics of the casing string.

Technology for well development using ultrasonic research method is described in [12]. The ultrasonic method is particularly effective in reducing hard mineral deposits. Its main effect extends beyond the well casing string into the gravel area. After using the ultrasonic method (as well as other mechanical methods), the well can be immediately put into operation. However, the ultrasonic method cannot be used on its own but only in combination with the pump (or airlift) method, which is used to remove material released by the ultrasonic effect itself. Among the most significant results of sanitation of an experimental well using ultrasound is a decrease in additional resistance and an increase in specific flow rate, which are accompanied by a noticeable decrease in density in the filtration zone of the well.

Implosion impact is one of the most effective techniques of well development [13, 14]. However, its use is hampered by the complexity of the design of existing devices, the high cost of their use, and insufficient operational reliability [15, 16]. The proposed device is simpler in structure, as well as cheaper and more reliable in use.

A mechatronic system for implosion impact on the bottomhole formation zone was proposed in [17]. The proposed generator makes it possible to provide multiple implosion impacts on the bottomhole zone of the formation. The necessity of using an automatic generator control system was substantiated. The dependence of the pressure in the front wave of the hydraulic shock on the diameter of the implosion chamber of the generator was determined analytically – a hyperbolic dependence, and the pressure in the front wave of the hydraulic shock on the immersion depth of the generator – a directly proportional dependence. The developed control algorithm makes it possible to automate the process of processing an oil well and optimize the processing time and its intensity depending on mining and geological conditions.

It should be noted that the implosion impact not only affects the aquifer, increasing its permeability, but also affects the casing string, which can lead to its collapse and loss of integrity. Thus, an unsolved problem is to maximize the implosion impact on the aquifer, taking into account the limitations imposed by the strength characteristics of the casing string.

3. The aim and objectives of the study

The purpose of this work is to identify the features of using a new device for implosion impact on an aquifer. This will make it possible to achieve maximum decolmatization of the productive formation, restore its natural permeability, and thereby ensure high well production and its long-term trouble-free operation.

To achieve this goal, the following tasks were solved:

– to examine the maximum permissible size of the casing string interval not filled with liquid;

– to study the influence of the size of the interval not filled with liquid on the Archimedean force acting on the casing string;

– to determine the parameters for the new device under the conditions of the Tonirekshin tract (Mangistau Peninsula);

– to analyze the interaction of the bailer valve with the inlet valve.

4. The study materials and methods

The object of our study is the parameters of the device for implosion impact on aquifers during well development in relation to the conditions of the Tonirekshin field.

The research was based on the idea of maximizing the implosion impact on the aquifer, taking into account the preservation of the strength characteristics of the casing string.

The following assumptions and simplifications have been accepted.

The casing string was considered as a solid thin-walled cylinder of a rectilinear shape, having equal strength along its entire length.

The bailer was considered as a thin-walled cylinder of rectilinear shape.

When conducting research, the friction force between moving mechanisms and liquids was assumed to be negligible.

The productive formation was considered to have the same properties throughout its thickness.

To solve the problems, the following research methods were used:

1. System analysis of reports on exploration work at the Tonirekshin field. The results of drilling and development of water wells previously drilled in the study area were studied. The reasons for the low production rate of wells have been identified. This served as the basis for the development of new techniques for influencing productive formations.

2. Devising a methodology for analyzing the operation of an implosion impact device on productive horizons by analyzing the interaction of the device and the working fluid.

5. Results of investigating the operating parameters of a device for implosion impact on an aquifer

5. 1. Determining the maximum permissible size of the casing string interval not filled with liquid

The implosion method involves creating a depression on the formation by instantly connecting the productive zone of the well, which is under formation pressure, with a low-pressure zone.

To use this method when developing water wells, an original device was proposed [3]. In this device, space 10 unfilled with drilling fluid is left in the production casing 1 (Fig. 1). The receiving part of well 2 is separated from the casing string 1 by partition 6. An inlet valve 7 is mounted on it. Fig. 3 shows how, when the valve is in a closed position, its disk 7 covers holes 12 in partition 6. The disk is pressed against the partition by reservoir pressure, as well as by spring 11. Under the weight of the bailer lowered onto the valve, it opens, connecting the receiving part with the low-pressure zone and causing a sharp influx of water from the reservoir. The annular space of the receiving part is isolated from the same space of string 1 (Fig. 1) by an elastic packer 5, activated by the weight of the casing string. Rational parameters of elastic packers can be determined based on their modeling [18].

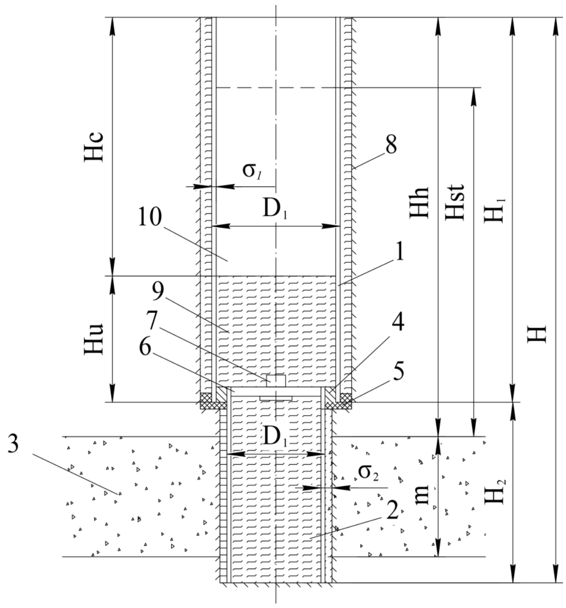

Fig. 1. Device for generating an implosion impact: 1 – production casing; 2 – filter column; 3 – aquifer; 4 – sub; 5 – packer; 6 – partition; 7 – inlet valve; 8 – borehole wall; 9 – drilling fluid; 10 – air; 11 – aquiclude; H – well depth; H_h – depth of the aquifer; m – power of the aquifer; H_1 – production casing length; H_2 – length of the filter column; H_{st} – static head of the formation; H_c – critical length of the empty part of the column; H_u is the height of the drilling fluid above the partition; D_1 – outer diameter of the production casing; D_2 – the same for the filter column; σ_1 – wall thickness of the production casing; σ_2 – the same for the filter column

When the casing string is lowered, the drilling fluid it displaces remains in the annulus and fills it to the mouth. The hydrostatic pressure created by this drilling fluid, acting externally on the part of the string left unfilled, can crush it.

Safety factor of the casing string for collapse [19]:

$$n_f = \frac{p_{mpp}}{P_f}, \tag{1}$$

where p_{mpp} is the maximum permissible pressure, and P_f is the actual pressure difference between the outside and inside the casing string.

Formula (1) for determining p_{mpp} includes: σ_y – yield strength of steel; E – its modulus of longitudinal elasticity; D_n – rated outer diameter of the pipe; $D_{\min}$ and $D_{\max}$ are the limits of this diameter allowed by manufacturing conditions; σ, σ_0, $\sigma_{\min}$ – rated, average statistical and minimum permissible wall thicknesses. It is recommended to accept: $\sigma_0=0.905\sigma$, $\sigma_{\min}=0.875\sigma$ [20].

The following combinations of initial values have been introduced:

$$K_0 = \frac{\sigma_0}{D_n},\ K_{\min} = \frac{\sigma_{\min}}{D_n},\ \rho = \frac{\sigma_0}{\sigma_{\min}},$$

$$B = EK_0^2\rho,\ e = \frac{D_{\max} - D_{\min}}{D_n}. \tag{2}$$

The values of the maximum permissible ovality for different diameters of casing pipes are given in Table 1 [21].

Table 1

Maximum ovality of casing pipes

Outer diameter D, mm	To 219	219–324	exceeding 324
Ovality, e	0.01	0.015	0.02

A more complex auxiliary combination is also introduced:

$$A = \sigma_y + B\left(1 + \frac{3e}{2\rho^3 K_{\min}}\right). \tag{3}$$

Finally, we have:

$$p_{mpp} = 1.1K_{\min}\left(A - \sqrt{A^2 - 4\sigma_B B}\right). \tag{4}$$

The actual n_f values must satisfy the condition:

$$n_f \geq n_{\min}. \tag{5}$$

With this in mind, the critical value of the pipe collapse pressure:

$$p_c = \frac{p_{mpp}}{n_{\min}}. \tag{6}$$

The minimum allowable safety factor of pipes are given in Table 2 [22].

Table 2

Minimum allowable safety factor of pipes $n_{\min}$

Casing type	Safety factor $n_{\min}$
Production casing	1.3
Intermediate casing	1.1

Under the conditions of the well, the critical pressure of the pipe collapse:

$$P_c = \rho_f g H_c, \tag{7}$$

where ρ_f is the density of the drilling fluid, g is the acceleration of free fall; H_c – permissible height of empty space 10 (Fig. 1):

$$H_c = \frac{p_c}{\rho_f g}, \tag{8}$$

$$H_u = H_1 - H_c. \tag{9}$$

Depression causing implosion effects is equal to:

$$P_D = p_h - p_f g H_u, \tag{10}$$

where p_h – reservoir pressure.

When lowering the column, it is necessary to pour the volume of the drilling fluid into it:

$$V_u = \frac{\pi}{4}\left(D_1 - 2\sigma_1\right)^2 \cdot H_u. \tag{11}$$

This amount of topped up drilling fluid will ensure the creation of the maximum implosion impact on the productive reservoir and will not allow the crushing of the unfilled part of the casing.

5. 2. Influence of the casing string interval unfilled with liquid on the Archimedean force acting on it

Weight of the double casing string (Fig. 1):

$$M_{cs}=\frac{\pi}{4}\begin{pmatrix}\left(D_1^2-\left(D_1-2\sigma_1\right)^2\right)H_1+\\+\left(D_2^2-\left(D_2-2\sigma_2\right)^2\right)H_2\end{pmatrix}\rho_s K_j, \qquad (12)$$

where ρ_s is the steel density, K_j is a coefficient that takes into account the mass of the joints.

Total weight of casing string in air:

$$G_{cs}=M_{cs}g. \qquad (13)$$

The Archimedes force acting on the string is equal to:

$$G_A=\frac{\pi}{4}\begin{pmatrix}\left(D_1^2-\left(D_1-2\sigma_1\right)^2\right)H_1+\\+\left(D_2^2-\left(D_2-2\sigma_2\right)^2\right)H_2+\\+\left(D_1-2\sigma_1\right)^2 H\end{pmatrix}\rho_f g K_j. \qquad (14)$$

The actual weight of the casing in the well is:

$$G_{csA}=G_{cs}-G_A. \qquad (15)$$

Thus, with increasing length of the interval not filled with liquid, the buoyant force acting on the casing string increases significantly, reducing the actual weight of the casing string in the well.

5. 3. Application of a methodology for analyzing the operation of an implosion device to the conditions of water wells in the Tonirekshin area of the Mangistau Peninsula

The parameters of a typical well for drilling under the conditions of the Mangistau Peninsula, given in Tables 3, 4, were justified in [2].

The results of calculations of the casing string for collapse for a column with a diameter of 168 mm are given in Table 5.

Similar calculations are performed for the case when the production casing is made of pipes with a diameter of 127 mm (Table 6).

Table 3

Parameters of a typical well

No.	Parameter	Unit	Value
1	Well depth, H	m	490
2	Upper interval depth, H_1	m	425
3	Diameter of the upper interval, D_{W1}	mm	243
4	The diameter of the production casing, D_1	mm	168
5	Diameter of the lower interval, D_{W2}	mm	151
6	Diameter of the filter column, D_2	mm	127
7	Winding filter diameter, D_f	mm	134
8	The depth of the roof of the reservoir, H_h	m	430
9	Reservoir thickness, m	m	40
10	Permeability coefficient K_f	m/day	4.2
11	Static reservoir head H_{st}	m	403
12	Reservoir pressure, P_h	MPa	3.95
13	Drilling fluid density, ρ_f	kg/m^3	1030

Table 4

Additional parameters

No.	Parameter	Value
1	Modulus of longitudinal elasticity, E, Pa [23]	$2\cdot10^{11}$
2	Yield point, σ_y, Pa	$5\cdot10^{7}$
3	Steel density, ρ_s, kg/m^3	7850
4	Density of water, ρ_w, kg/m^3	1000
5	Ovality of the pipe, e	0.01
6	Minimum pipes safety factor, $n_{\min}$	1.3
7	String wall thickness 168 mm, σ_1, mm [24]	6.5, 7, 8, 9, 10, 11, 12
8	Ditto columns 127 мм, σ_2, mm	5, 6, 7, 8, 9

Table 5

Dependence of the parameters of the calculation of the casing for collapse on the wall thickness of the pipe

Parameter	Wall thickness σ_1, mm						
	6.5	7	8	9	10	11	12
P_{mpp1}, MPa	2.54	2.82	3.37	3.92	4.47	5.04	5.60
P_{c1}, MPa	1.96	2.16	2.59	3.02	3.44	3.87	4.30
H_{c1}, m	194	214	256	298	340	383	424
H_{u1}, m	236	216	174	132	90	47	6
V_{u1}, m^3	4.45	4.02	3.16	2.33	1.55	0.79	0.07
P_{D1}, MPa	1.57	1.77	2.19	2.62	3.04	3.48	3.91

Table 6

Difference in strength characteristics

Pressure	Pipe diameter, D, mm	Wall thickness, σ, mm		
		7*	8	9
P_c, MPa	127	3.13	3.70	4.26
	168	2.16	2.59	3.02
P_D, MPa	127	2.73	3.29	3.86
	168	1.77	2.19	2.62

*Note: * – only common wall thicknesses for pipes of 168 and 127 mm are given*

A comparison of the strength characteristics of pipes with a diameter of 168 mm and 127 mm is shown graphically in Fig. 2.

An increase in wall thickness by 1.85 times corresponds to an increase in critical pressures P_{mpp}, P_c and the critical interval H_c by 2.2 times, and a differential pressure P_D by 2.49 times. The required height of the drilling fluid above the partition H_u dropped from 236 to 6 m.

The comparison showed that 127 mm pipes have higher crush resistance than 168 mm pipes. Thus, for P_c, the advantage is on average 43 %, and for P_D – 50 %.

In the combined column shown in Fig. 1 only the 168 mm column is at risk of collapse. As a result, a minimum wall thickness of 5 mm was selected for the filter column.

To assess the effect of empty space on the weight of the column (14), a coefficient of increase in its mass due to joints is required:

$$K_j=\frac{M_j/L_{ct}+M_{1m}}{M_{1m}}, \qquad (16)$$

where M_j is the mass of the joint, M_{1m} is the mass of one meter of a casing string pipe [25], L_{ct} is the average length of one pipe.

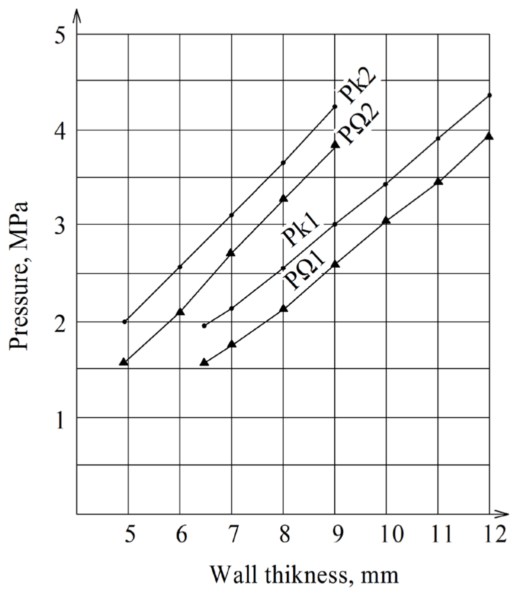

Fig. 2. Comparison of strength characteristics of pipes with a diameter of 168 mm (index 1) and 127 mm (index 2)

For pipes of 168 m, M_j=9.1 kg, for pipes of 127 m, M_j=6.0 kg. On light water drilling rigs, L_{ct}=6 m.

The results of calculations of the Archimedean force in relation to typical conditions of the Tonirekshin site are given in Table 7.

Table 7

The influence of the Archimedean force on the weight of the column

D/H,* mm/m	Parameter	σ, mm						
		6.5	7	8	9	10	11	12
168/425	G_{cs}^{**}, kN	114	122	138	153	168	184	195
	G_A, kN	14.9	16.1	18.1	20.1	22.2	24.1	25.5
	$G_{\Delta A}$, kN	37.0	40.3	47.0	53.3	59.1	64.8	70.1
	G_{csA}, kN	62.1	65.6	72.9	79.6	86.7	95.1	99.4
	G_{csA}/G_{cs}	0.54	0.54	0.53	0.52	0.52	0.52	0.51
D/H, mm/m	Parameter	σ, mm						
		5	5**	5	5	5	5	5
127/65	G_{cs}, kN	9.6	9.6	9.6	9.6	9.6	9.6	9.6
	G_A, kN	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	G_{csA}, kN	8.4	8.4	8.4	8.4	8.4	8.4	8.4
Total 490 m	G_{cs}, kN	123.6	131.6	147.6	163.6	177.6	193.6	204.6
	G_A, kN	16.1	17.3	19.3	21.3	23.4	25.3	26.7
	$G_{\Delta A}$, kN	37.0	40.3	47.0	53.3	59.1	64.8	70.1
	G_{csA}, kN	70.5	74.0	81.3	88.0	95.1	103.5	107.8
	G_{csA}/G_{cs}	0.57	0.56	0.55	0.54	0.54	0.53	0.53

*Note: * – the numerator is the outer diameter, the denominator is the length of the column; ** – G_{cs} – weight of the column in the air, G_A – Archimedean force without taking into account empty space, $G_{\Delta A}$ – the same due to it, G_{OKA} – weight of the column in drilling fluid*

From Table 7, we can draw the following conclusions:

1. The total Archimedean force reduces the weight of the column by 43–47 %, depending on the geometric dimensions of the column.

2. It grows with increasing thickness of the pipe wall (Table 5).

3. Reducing the weight of the casing reduces the required power of the winch, which is important when using light drilling rigs.

5. 4. Interaction of the inlet valve and bailer

In the absence of contact with the bailer, the inlet valve is closed under the action of the differential pressure directed at its disk 7 (Fig. 3) from bottom to top (formula (10)), as well as the tension of spring 11. The differential pressure creates a force [26]:

$$F_{cl} = \frac{\pi}{4} D_V^2 P_D, \tag{17}$$

where D_V is the diameter of the valve disc.

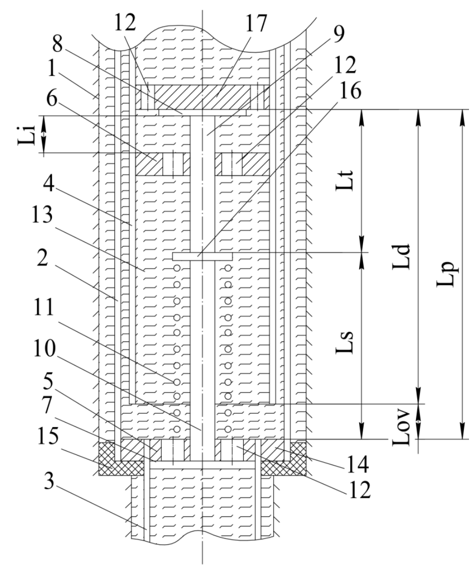

Fig. 3. Moment of the onset of an implosion impact: 1 – borehole wall; 2 – production casing; 3 – filter column; 4 – bailer; 5, 6 – partitions; 7 – intake valve disc; 8 – disk of the bailer valve; 9 – liner; 10 – rod; 11 – spring; 12 – holes; 13 – drilling fluid; 14 – adapter; 15 – packer; 16 – washer; 17 – stop; L_p – initial distance from the stop to partition 5; L_d – distance from the stop to the end of the bailer; L_t – liner length; L_s is the length of the uncompressed spring; L_{ov} – amount of lowering of the intake valve disc

The weight of the disk with rod 10 acts in the direction of opening the valve but it is small compared to the force of the differential pressure.

To open the valve with a bailer, its weight must meet the condition:

$$G_b > F_{cl}. \tag{18}$$

The bailer is lowered into the well and stopped at a distance of 1–1.5 m from the inlet valve. By small bleedings of the rope with a winch, we reach the moment when liner 9 of the bailer valve touches the upper end 16 of spring 11. During further bleedings, spring 11 and the inlet valve itself remain stationary, but at the same time liner 9 with disk 8 moves upward relative to the end of the bailer. This movement continues until stop 17. After this, the weight of the bailer begins to act on rod 10, opening the inlet valve. The pressure under the partition rapidly drops, the reservoir pressure is instantly replaced by differential pressure P_D, creating an implosion impact. Between the moments of the first contact of liner 9 with spring 11 and the opening of the inlet valve, the bailer is lowered by the amount:

$$L_b = L_i + L_{ov}, \tag{19}$$

where L_i is the «idling» (no load) of disk 8 from partition 6 to stop 17, and L_{ov} is the lowering of disk 7 of the intake valve when it is fully open.

If the full possible compression of the spring is too short, the bailer will hang on the spring and its end will not reach the partition. The spring may be broken. Therefore, L_{ov} should be only a part of its possible compression, taking into account additional pre-compression to keep the valve closed. Based on these conditions, the required length of the spring is determined.

The specified opening of the valve L_{ov} will be ensured if stop 17 is mounted at the following distance from the end of the bailer:

$$L_d = L_t + L_s - L_{ov}, \tag{20}$$

where L_s is the length of the spring before contact with the bailer, L_t is the length of liner 9.

Formulas (17) and (18) allow the given diameter of the intake valve disk to determine the force required to open it. If the weight of the bailer itself turns out to be insufficient, then it should be lowered on drill pipes attached to the top on a rope. Required pipe length:

$$L_{ds} = \left(\frac{\pi}{4} D_v^2 P_D - G_f\right) \Big/ \left(M_{1ds}\left(1 - \frac{\rho_f}{\rho_s}\right) g\right), \tag{21}$$

where M_{1ds} is the mass of 1 m of drill pipe [25].

Pressure loss at ports [27] of the intake valve:

$$P_v = \frac{Q^2 \rho_w}{2\alpha^2 S^2} \text{ or } P_v = \frac{V_v^2 \rho_w}{2\alpha^2}, \tag{22}$$

where Q is the flow rate of formation water; V_v is the speed of its movement through the holes; ρ_w – its density; α – flow coefficient – we take α=0.67 [28]; S – total area of holes.

As the flow rate, we shall take its maximum possible value under the given conditions, defined in m^3/h as [29]:

$$Q = \pi D_f m V_f, \tag{23}$$

where D_f is the filter diameter, m is the thickness of the aquifer, V_f is the permissible filtration rate. The latter in m/h is defined as [30]:

$$V_f = 2.71\sqrt[3]{K_f}. \tag{24}$$

The maximum possible area of the holes for a given diameter of the intake valve disc (Fig. 4):

$$S = \frac{\pi}{4}\left(D_{vo}^2 - D_{vi}^2\right) - \frac{3\left(D_{vo} - D_{vi}\right)\sigma_p}{2}. \tag{25}$$

To produce a repeated implosion impact, the bailer is removed from the well (and spring 11 closes the inlet valve) and the water is scooped out with it until the height of the water above the partition reaches a given value H_u. The latter should be adjusted by:

$$H_{uv} = \frac{{}_u\rho_w}{\rho_w}, \tag{26}$$

because with repeated implosion effects, the drilling fluid will be removed.

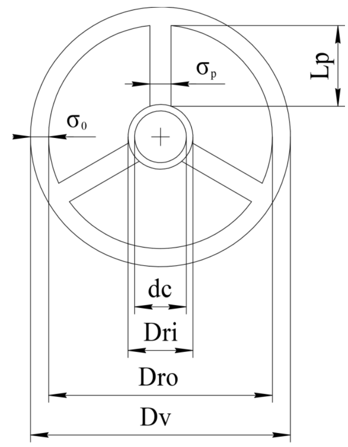

Fig. 4. Shape of the intake valve holes: D_v — diameter of the valve disc; D_{ro} — outer diameter of the annular hole; D_{ri} is its internal diameter; d_C — diameter of the vertical valve rod; σ_0 — distance of the hole from the edge of the disk; σ_p — thickness of the partition; L_p — length of the partition

Next, the bailer is again lowered onto the inlet valve and the implosion impact is repeated.

When scooping, the number of bailer trips should be equal to [31]:

$$N_b = \frac{\pi/4 \cdot D_{i1}^2\left(H_{st} - H_{uv}\right)}{\pi/4 \cdot \left(D_b - 2\sigma_b\right)^2 L_b}, \tag{27}$$

where D_{i1} is the internal diameter of the casing string, D_b and σ_b are the outer diameter and wall thickness of the bailer L_b is the length of the bailer.

Our methodology was used in relation to typical conditions of the Tonirekshin site (Tables 3, 4, 8).

Table 9 gives the force F_{cl} (17) acting from below on the inlet valve, as well as the footage L_{ds} (21) of 73 mm pipes with which it is necessary to weight the bailer. The corresponding number of drill pipes N_p is given rounded up.

Also given are the total areas S_v of the inlet valve passage openings (25) and Fig. 4, the speed V_v of water movement in them, and the corresponding pressure loss P_v at the inlet valve (22).

From Table 9, it follows that with valve diameters of 30 and 40 mm, the weight of the bailer is sufficient to open it, and the pressure loss at maximum inflow is very large. When D_v increases from 50 to 100 mm, i.e., by 2 times, the required footage L_{ds} of added drill pipes increases by 13.3 times, the area of the holes S_v – by 5 times, and the pressure drop P_v decreases by 24 times. As an optimal option, we can recommend D_v=70 mm, at which it is necessary to add only 6 drill pipes to the bailer with a pressure loss of only 0.054 MPa.

Table 8

Source data

No.	Parameter	Value
1	The outer diameter of the production casing, D_1, mm	168
2	Production casing wall thickness, σ_1, mm	9*
3	Inner diameter of the production casing, D_{i1}, mm	150
4	The height of the liquid column above the partition, H_u, m	132
5	Reservoir pressure, P_h, MPa	3.95
6	Differential pressure, P_D, MPa	2.62
7	The diameter of the bailer, D_v, mm	146
8	The thickness of its wall, σ_v, mm	11
9	Its length, L_v, m	12
10	The weight of the bailer, taking into account the Archimedean force, G_v, kN	3.88
11	Drill pipe diameter, D_{ds}, mm	73
12	The mass of its meter, taking into account the joints, M_{1ds}, kg	19.8
13	Aquifer capacity, H_h, m	40
14	Permeability coefficient, K_f, m/day	4.2
15	Maximum permissible water inflow, Q, m^3/h	73.4**
16	Drilling fluid density, ρ_f, kg/m^3	1030
17	Indentation of holes from the diameter of the valve disc, σ_0, cm	0.20
18	Diameter on the inside of the holes, D_{ri}, cm	1.00
19	The width of partitions in the valve holes, σ_p, cm	0.5

*Note: * – the option with an average wall thickness is accepted – Table 4*

Table 9

Dependence of the parameters of the intake valve on the diameter of its disc

Parameter	D_v, mm							
	30	40	50	60	70	80	90	100
F_{cl}, kN	1.85	3.29	5.14	7.40	10.08	13.16	16.66	20.57
L_{ds}, m	0	0	6.5	18.2	32.1	48.1	66.2	86.5
N_p, pcs.	0	0	2	4	6	9	12	15
S_v, cm^2	3.32	7.44	13.13	20.38	29.21	38.61	51.57	65.11
V_v, m/s	61.40	27.4	15.53	10.00	6.98	5.28	3.95	3.13
P_v, MPa	4.200	0.836	0.268	0.111	0.054	0.031	0.017	0.011

When scooping water from a well before carrying out repeated implosion impact, the required number of bailer runs (without weights) according to formula (27) is equal to 33. In this case, the value of H_{uv}=136 m, calculated by formula (26).

6. Discussion of results of investigating the parameters of the device for implosion impact on the aquifer

There are a large number of different methods for developing aquifers. They are aimed at removing colmatation products and restoring the natural permeability of the formation. Choosing the optimal method for the conditions of a particular field makes it possible to achieve high productivity and operating efficiency of a water intake well for a long time. It was justified that for the conditions of the Mangistau Peninsula of the Republic of Kazakhstan, the most effective is the implosion impact on aquifers [3].

An original device structure was designed to generate an implosion impact on productive horizons (Fig. 1).

As a result of determining the maximum permissible size of the casing string interval not filled with liquid, it was found that with an increase in the casing string interval not filled with liquid, the implosion impact increases. The limiting factor is the crushing strength of the casing string.

The presence of an interval of the casing string that is not filled with liquid leads to an increase in the Archimedean buoyancy force (14), which significantly reduces the actual weight of the string.

The devised methodology for analyzing the operation of the implosion device was applied to the conditions of water wells at the Tonirekshin site. The parameters of a typical well for drilling under the conditions of the Mangistau Peninsula, given in Tables 3, 4, were justified in [2]. For these conditions, the dependence of the parameters for calculating a casing string with a diameter of 168 mm for crushing on the thickness of the pipe wall was determined, given in Table 5. Comparison of the strength characteristics of pipes with a diameter of 168 mm and 127 mm (Fig. 2) showed that 127 mm pipes have higher crush resistance than 168 mm pipes. Thus, the advantage in terms of critical pipe collapse pressure is on average 43 %, and in terms of differential pressure 50 %.

Taking into account the influence of the Archimedean force on the weight of the column (Table 7) showed that the weight of the column decreases by 43–47 % depending on the geometric dimensions of the column and increases with increasing pipe wall thickness.

An analysis of the interaction between the inlet valve of the designed implosion device and the bailer was carried out in relation to the typical conditions of the Tonirekshin site (Tables 3, 4, 8). Analysis of the dependences of the operating parameters of the intake valve on the diameter of its disk (Table 9) allowed us to establish the following. First, the force acting from below on the intake valve increases as the diameter of the intake valve increases. Secondly, the speed of water movement in the passage openings of the inlet valve and the corresponding pressure loss across the inlet valve are reduced.

Unlike existing devices for implosion impact on aquifers [15, 16], the proposed device is simpler in structure, as well as cheaper, and more reliable in use. This was made possible by eliminating special strings and a mechanical packer from the design, as well as using a bailer to open the inlet valve.

This simplification of the structure means a significant expansion of the practical applicability of this technology in production environments. The proposed procedure for selecting the parameters of an implosion device makes it possible to achieve the maximum positive effect under specific geological and technical conditions. This was illustrated for the conditions of the Tonirekshin field on the Mangistau Peninsula.

The use of the designed implosion device is limited to aquifers represented by either loose granular or fractured rocks. This is explained by the mechanism of implosion impact on the aquifer. In porous horizons, it would be more rational to use other well development methods [14].

A certain disadvantage of this study is that the processes occurring in the aquifer as a result of the impact of the designed implosion device on it were not studied.

Further research should be aimed at optimizing the frequency-amplitude impact depending on the reservoir characteristics of the aquifer. This will allow the development process to be carried out faster and to achieve maximum use of the productive potential of the reservoir.

7. Conclusions

1. The problem of collapse of casing strings by differential pressure arising due to the creation in them of intervals not filled with liquid necessary for implosion impact has been studied. The permissible height of empty space in the casing string has been determined, ensuring the creation of the maximum implosion impact and preventing the column from collapsing. It directly depends on the thickness of the casing string wall and inversely on the density of the drilling fluid. The amount of drilling fluid required to add to the casing string to achieve these results was determined. It increases as the allowable void space in the casing string decreases.

2. The reduction in weight of casing strings under the influence of Archimedean force, due to the presence of empty intervals in them, was studied. It was revealed that with increasing length of the interval not filled with liquid, the buoyant force acting on the casing string increases significantly, reducing the actual weight of the casing string in the well.

3. In relation to the conditions of the Tonirekshin field, an optimal well structure has been suggested, including the proposed device for creating an implosion impact. The critical dimensions of empty intervals were calculated for all wall thicknesses of casing string pipes included in the well structure. It has been established that the amount of weight reduction of the casing string in the well due to the Archimedean force for field conditions is 43–47 %, depending on the geometric dimensions of the string. Archimedean force increases with increasing pipe wall thickness. Reducing the weight of the casing string reduces the required winch power, allowing wells to be drilled using lighter drilling rigs.

4. As a result of studying the interaction of the bailer with the inlet valve of the designed device, the following was established. For the bailer to open the valve, its weight must exceed the force created by the differential pressure of the drilling fluid on the inlet valve. If this weight turns out to be insufficient, the bailer should be weighted with drill pipes, the required length of which depends on the density of the drilling fluid, the density of the material of the drill pipes and the required amount of weighting. To reduce the pressure drop across the intake valve, one should strive to increase the total area of its openings, which is limited by the geometric dimensions of the valve. As the valve diameter increases, the pressure drop decreases. To achieve a repeated implosion impact, it is necessary to use a bailer to scoop out the water that entered the well after the previous impact. The number of runs required for this depends on the inner diameter of the casing string, the outer diameter, and wall thickness of the bailer, as well as the length of the bailer.

Thanks to our results, it is possible to achieve the maximum implosion impact through repeated effect of the productive formation without the risk of damaging the casing string.

This is explained by the fact that repeated exposure to the productive formation ensures effective removal of clogging material from the reservoir and cleaning of the productive horizon to a much greater depth compared to a single exposure.

The above provisions are illustrated by an example of a calculation for the specific conditions of the Tonirekshin field, which made it possible to select the optimal diameter of the inlet valve, the required length of drill pipes to weight the bailer, as well as the number of bailer runs before implementing repeated implosion impacts.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

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