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CREATION OF A CRYOGENIC-GRAVEL FILTER OF THE REQUIRED STRENGTH AND DESIGN CONFIGURATION

Purpose. The study aims to enhance the performance of groundwater abstraction wells fitted with gravel-packed filtration systems by increasing water production rates and ensuring higher-quality water supply for communities in the Republic of Kazakhstan.

Methodology. The study carried out a comprehensive analysis of existing gravel filter designs and the features of their operation under sandy aquifer conditions. To verify the theoretical principles, experimental tests of gravel element samples were conducted: they were tested for compression both in a dry state and after water saturation. Additionally, analytical modeling of the process of gravel pack level reduction in the annular space of the well was performed.

Findings. A calculation approach was developed to assess the strength of the annular gravel elements of the filter. Experimental studies revealed the patterns of material strength reduction over time when in contact with water. It was established that the decrease in the gravel pack level is determined by the size of the gap between the casing and the filter, as well as by the length of the filtering section. To compensate for the losses, a technology for supplying an additional volume of gravel through the drill string was proposed, which makes it possible to restore the designed gravel pack level.

Originality. For the first time, a methodology for the dynamic assessment of the strength of cryogenic-gravel elements has been proposed, taking into account the processes of their disintegration in an aqueous environment. Analytical dependencies have been obtained that make it possible to predict the decrease in the gravel pack level depending on the geometry of the filter and the well parameters. A new technical solution has been developed aimed at stabilizing the gravel pack during operation.

Practical value. The obtained results are of interest to organizations engaged in the design, drilling, and construction of water intake wells. The application of cryogenic technology contributes to a more uniform distribution of the gravel pack, reduces the risk of loss of filtration properties, and ensures the durability of well operation.

Keywords: *gravel filter, cryogenic technology, gravel pack, water intake well, drinking water supply*

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Introduction. The operation of water intake wells in sandy aquifers is traditionally accompanied by a number of technological and operational problems. The most significant of these is ensuring the stable, reliable, and long-lasting performance of the filtration system, which directly determines the efficiency of groundwater resource utilization [1, 2]. Practice shows that to increase well productivity and improve the quality of the extracted water, the most widely used designs are wire-wrapped screens supplemented with a gravel pack. Such a design offers several advantages: the gravel serves as an additional natural barrier that traps sand and silt particles, reduces silting rates, and stabilizes the hydrodynamic parameters of well operation [3]. However, despite these obvious advantages, existing methods for forming the gravel pack still do not provide sufficient uniformity and reliability [4].

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One of the most commonly used methods is the injection of gravel through the annular space or its delivery via drill pipes. However, both options have significant drawbacks. The formation of the gravel pack is uneven: voids occur in some zones, while excessive compaction of the material is observed in others. In addition, part of the gravel is lost in the enlarged intervals of the wellbore [5, 6]. Such changes reduce the effective interaction area between the gravel envelope and the surrounding formation, negatively affecting the hydraulic performance of the well. Consequently, groundwater inflow becomes less efficient, water quality may decline, and the risk of clogging processes within the well structure increases.

An alternative solution has been the use of thin-walled metal shells that disintegrate upon contact with water, releasing the gravel pack. However, practice has shown that this method also has disadvantages. The process of shell disintegration occurs unevenly along the filter, causing chaotic gravel distribution and incomplete filling of the annular space [7, 8]. As a result, the expected improvement in operational reliability is not achieved. Moreover, this technology may lead to additional costs for repair and restoration work [9–11].

Modern developments in the field of gravel filter design still do not provide sufficient stability of the hydrodynamic characteristics of wells and do not guarantee long-term, trouble-free operation. In this regard, the scientific and technical objective is to develop new methods and technical solutions that eliminate the aforementioned shortcomings.

One of the promising directions is the use of cryogenic technology for forming the gravel pack. The essence of the method lies in the preliminary fabrication of annular gravel elements that are temporarily solidified using special binding substances. After the filter is lowered into the well and comes into contact with the aquifer, these blocks gradually lose their solidity, releasing the gravel and forming a uniform pack throughout the entire annular space [12–14]. Thus, uniform material distribution is achieved, contact with the aquifer is improved, and optimal filter performance is ensured.

The key scientific problem lies in the need to develop theoretical and practical foundations for calculating the strength of cryogenic-gravel elements at various stages of their disintegration under the influence of water. It is important to determine the patterns of strength variation over time, identify the factors affecting the uniformity of gravel distribution, and develop methods to compensate for possible reductions in the gravel pack level. An additional challenge is to find engineering solutions that minimize the risks of exposing the wire-wrapped base of the filter during operation [15].

Solving this problem has not only engineering but also social significance. Improving the reliability and durability of water intake wells is directly related to providing the population of Kazakhstan with high-quality drinking water resources. Thus, the development of innovative technologies in the field of gravel filters meets the strategic interests of the state and contributes to the rational use of natural resources [16].

Literature review. The problem of designing, installing, and improving gravel filters for water intake wells has remained one of the most discussed topics in hydrogeological and engineering literature over the past decades. Researchers in Kazakhstan and other countries emphasize that the operational reliability and durability of water intake systems directly depend on the quality of the filter and the proper arrangement of the gravel pack [17, 18]. Recent publications demonstrate a wide range of solutions – from improving the structural parameters of filters to optimizing the technological processes of their installation. The main focus is on ensuring uniform gravel distribution, selecting the appropriate grain size composition, and studying resistance to long-term exposure to the aquifer environment.

A significant influence on the development of this field was made by the works by A. A. Kozhevnikov and A. K. Sudakov, who proposed the concept of cryogenic-gravel filters. For the first time, the idea of temporary solidification of gravel elements was formulated – elements that retain their shape during transportation and lowering into the well, and then gradually disintegrate under the influence of filtering water. This technology makes it possible to eliminate the main drawback of traditional methods – the uneven formation of the annular space. In subsequent studies by Kozhevnikov, Otebayev, Sudakov, and Ratov, comprehensive research on the operational characteristics of gravel filters was carried out, confirming the universality of the cryogenic technology. The authors demonstrated that this approach can be applied not only in hydrogeological wells but also in production wells, which significantly expands its potential [19, 20].

A significant contribution to the theoretical study of gravel pack formation was made by B.V. Fedorov. In his works, the processes of gravel material sedimentation and distribution in the annular space were analyzed in detail, and the factors affecting the uniformity of the pack were identified. The researcher concluded that the non-uniform distribution of gravel is one of the key reasons for the reduced service life of filters and the deterioration of well performance indicators. These studies have become an important foundation for further work aimed at developing new technological solutions and calculation methods.

In the works by Bashkatov, Pankov, and their co-authors, special attention is given to the need for implementing innovative drilling and well construction methods that take into account the specific features of aquifers. The authors emphasize that minimizing gravel losses during pack formation is directly related to improving the operational reliability of the structures. Similar ideas can also be found in the fundamental publication “Hydrogeologist’s Handbook”. Despite the wide coverage of issues – from geological characteristics to engineering methods of well completion – the problem of uniform gravel packing around the filtration column remains unresolved. This confirms the necessity of developing new methods capable of eliminating this drawback and ensuring the stable operation of filtration systems [21–23].

Equally significant are the practical developments that have received legal protection. One of the notable achievements is the invention secured by Patent of the Republic of Kazakhstan No. 30818 [24]. It proposes an improved design of a gravel filter aimed at stabilizing the gravel pack level and preventing premature exposure of the filtering column. Similar technical solutions confirm that research in this field has high prac-

tical relevance and is in demand, especially under conditions of water intake system operation in sandy aquifers [25–27].

Summarizing the presented scientific publications and patent developments, it can be noted that, despite significant achievements, many issues remain unresolved. The most pressing task is the development of reliable calculation methods that allow predicting the process of formation and subsequent changes in the gravel pack, as well as the creation of engineering solutions that ensure uniform material distribution and the preservation of filtration properties over time [28]. Solving these tasks will make it possible to improve the reliability of drinking water supply systems, extend the service life of wells, and reduce operational costs [17, 29].

Purpose. The main goal of the study is to improve the efficiency of water intake wells equipped with gravel filters, specifically to increase the volume and improve the quality of the water extracted for the needs of the population of the Republic of Kazakhstan.

Problem statement. Although a variety of gravel filter designs are used in the practice of drilling and operating water intake wells, many unresolved issues remain that significantly reduce their efficiency. These shortcomings affect both the volume and quality of the extracted water, as well as determine the durability of well operation and the level of operational costs. Therefore, there is an objective need to develop new approaches – both engineering and technological – that can ensure the reliability of filtration systems throughout their entire service life.

One of the most significant problems is the uneven formation of the gravel pack in the annular space. When using traditional methods, such as injecting gravel through the annular space or delivering it via drill pipes, achieving a uniform distribution of material is rarely successful. As a result, voids and zones of increased density form, and sometimes areas with insufficient gravel are present. This leads to a disruption of the homogeneity of the filtering layer and a reduction in its permeability. The contact surface between the gravel and the aquifer decreases, which results in a reduction of well output and an increased likelihood of silting. Subsequently, this necessitates additional restoration measures, increasing the operational costs.

Another critical factor negatively affecting filter performance is the insufficient strength of temporarily solidified gravel elements. Initially, these blocks have adequate stability, but under the influence of well water, they gradually lose their strength properties. In some cases, block disintegration begins significantly earlier than the calculated service life, disrupting the designed structure of the filter and leading to a partial loss of its filtration characteristics. This reduces the efficiency of water intake and accelerates the aging process of the well, which is especially critical for centralized water supply systems.

Particular attention should be given to the problem of gravel pack level reduction during the disintegration of annular blocks. When the pack settles below the designed level, part of the wire-wrapped filter base remains exposed. This leads to a deterioration of the system's operational characteristics: hydraulic resistance increases, abrasive wear of filter elements intensifies, and the service life of the entire well is reduced. These changes negatively affect both the technical and economic performance of the operation.

The issues outlined above highlight the necessity of introducing advanced technological approaches to improve both the formation and long-term stability of gravel packs. Particular attention should be given to achieving a homogeneous distribution of gravel within the annular space while maintaining the mechanical integrity of temporary gravel structures during their operational period in the well. In addition, methods need to be developed to compensate for the reduction of the gravel pack level during operation.

Solving this problem will significantly increase well flow rates, reduce the risk of silting, and lower maintenance costs. The implementation of innovative technologies will ensure more durable operation of filtration systems and improve the economic efficiency of water intake facilities. Beyond its engineering significance, this issue also has a social dimension: the reliable operation of water intake wells is directly linked to the quality and uninterrupted supply of drinking water to the population. Therefore, improving gravel filter formation technologies contributes to the rational use of groundwater resources and strengthens the country's water security.

Research results and their analysis. Before proceeding to the description of the results, it is advisable to consider in more detail the essence of cryogenic technology, which in recent years has gained wide recognition as one of the most promising directions in the field of gravel filter design. The main idea of the method is that the key elements of the filter – annular gravel discs – are pre-fabricated under controlled conditions on the surface and brought to a monolithic state by introducing special binding or adhesive components into the gravel mass (for example, a gelatin solution or similar organic materials). Such additives provide temporary bonding of the particles and give the structure the necessary mechanical strength.

The resulting monolithic elements have sufficient stability to be mounted on the wire-rod frame of the filtration column and lowered into the aquifer interval. Thus, the filter is lowered into the well already assembled, which facilitates installation and minimizes the likelihood of damage to individual parts of the structure during lowering operations [12, 13]. Once in the well and exposed to filtering water over a specified period, the binding material gradually begins to disintegrate. As a result, the annular gravel discs lose their monolithic structure and transform into a loose gravel pack, which uniformly fills the annular space.

The main advantage of this technology lies in the combination of two opposite processes: the creation of a strong monolith during fabrication and transportation, followed by its controlled disintegration directly in the filtration zone. This ensures the formation of a uniform gravel pack, minimizes the risk of voids, and guarantees a high level of reliability of the filtration system. In addition, the quality of the resulting filters significantly surpasses that of traditional counterparts, allowing for a considerable increase in the trouble-free service life of water intake wells and a reduction in their repair and maintenance costs.

The fabrication of annular gravel discs for the filter occurs in several stages. In the first stage, a mold is cre-

ated to form the annular disc (Fig. 1) [14, 15]. When designing the mold, the height and diameter of the hollow cylinders are taken into account, which directly depend on the specified dimensions of the future filter elements, the allowable weight of each disc, as well as the calculated strength and ease of installation. In the second stage, the gravel mass with the added binding material is loaded into the mold and subjected to a pressing or compaction process. After hardening, the finished monolithic elements are obtained, which are assembled by threading onto the filtration column frame. This method ensures geometric accuracy, manufacturability, and the possibility of mass production of elements, which is especially important for the industrial construction of water intake facilities.

The subsequent technology for producing an annular disc includes the following operations: preparation of the gravel material and mineral-binding adhesive (for example, gelatin) and the preparation of the corresponding mixture (gravel, sand, and water) in accordance with (Table) [27]; mixing the mixture with a mixer, allowing it to thicken, and forming the cryogenic-gravel filter elements; drying the samples in a drying chamber at a temperature of +120 to +160 °C for 24 hours. The final operation involves removing the annular filter element, performing an external inspection, and conducting quality control (checking for cracks, voids, cavities, etc.). The presence of such defects serves as a signal for rejection, meaning that the use of such an element in subsequent applications is not allowed [28].

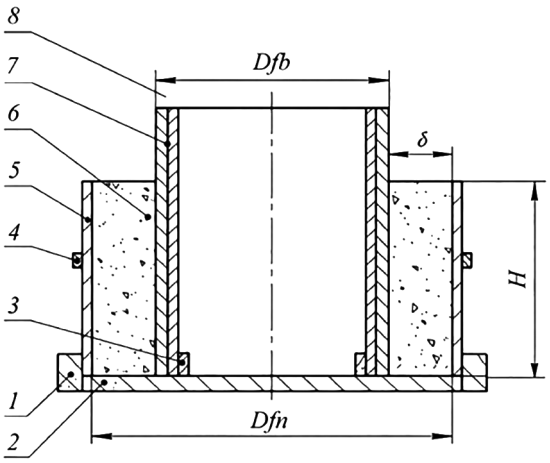

Fig. 1. Diagram of the mold for manufacturing annular filter disc elements:

H – height of the gravel pack; d – thickness of the gravel pack along the radius: 1 – outer cylinder stopper; 2 – mold base; 3 – inner cylinder stopper; 4 – connecting clamp; 5 – outer cylinder; 6 – cryogenic-gravel filter element; 7 – inner split cylinder; 8 – inner solid cylinder

Table

Mass of materials required for the fabrication of a cryogenic-gravel filter

Sand, g	Gelatin, g	Water, ml	Weight concentration of gelatin in water, %
5,000	60	1,140	5
5,000	120	1,030	10
5,000	180	1,020	15
5,000	240	960	20
5,000	300	900	25

Before fabricating the annular gravel discs, their geometric parameters must be determined, i.e., the outer diameter D_{out}, inner diameter D_{in}, and height H. Since the manufactured annular discs are mounted on a wire-frame structure located on the filtration column, the outer diameter of the filter disc D_{out} must be smaller than the inner diameter of the casing column by approximately $2d \approx 15–20$ mm. For example, if the outer diameter of the filter D_{out} is to be lowered inside a casing column with diameters 219/205 mm, then D_{out} should be $D_{out} = 205 - 20 = 185$ mm, and the standard bit diameter for penetrating the aquifer would be 190 mm.

The inner diameter of the annular elements must be slightly larger than the diameter of the wire-frame filter base, onto which the annular gravel disc is usually mounted. Its value is determined by the following formula.

$$D_{inf} = d_0 + 2a + 2b + 3, \quad (1)$$

where a is the diameter of the longitudinal rods (can be taken as ($a = 3$) mm); b is the diameter of the wire (can be taken as ($b = 2$) mm); d_0 is the diameter of the perforated frame (according to repair conditions), $d_0 > 100$ mm; for example, we take $d_0 = 127$ mm. Then the inner diameter of the filter disc is calculated as $D_{inf} = 127 + 3 \times 2 + 2 \times 2 + 3 = 140$ mm.

The thickness of the gravel pack will be $\delta = (180 - 140) = 20$ mm.

The height (H) of the fabricated annular elements is usually taken as ($H = 400–500$) mm. The annular monolithic gravel discs, manufactured using the aforementioned technology, are delivered to the drilling site and mounted on the wire-frame structure located on the filtration column (Fig. 2).

When the filter is lowered into the well, the strength of the annular gravel blocks decreases under the influence of water. To assess this parameter, cubes measuring

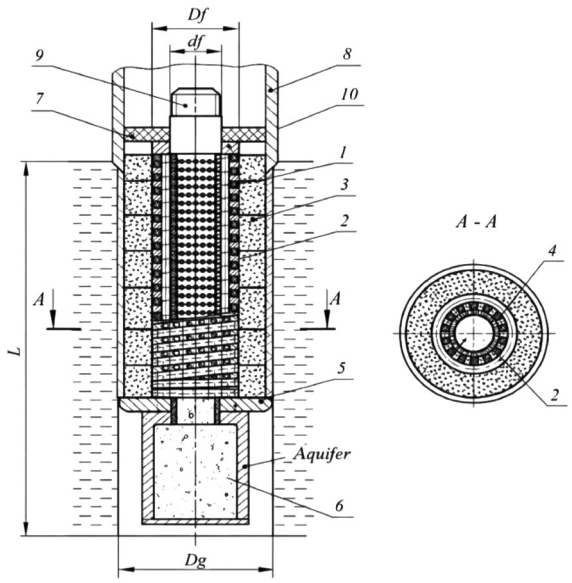

Fig. 2. Placement of the gravel filter in the aquifer interval:

1 – perforated frame; 2 – wire winding; 3 – casted ring gravel discs (gravel filter blocks); 4 – steel rods; 5 – lower stop; 6 – sediment tank; 7 – oil seal; 8 – water lifting column; 9 – filter column; 10 – upper stop

50 × 50 × 50 mm are fabricated on the surface and tested for compression on a press, initially in a dry state (after removal from the drying oven). This procedure is then repeated after immersing the cubes in water (a bath) for various fixed time intervals.

As a result, an experimental dependence of the form $\delta_{cs} = \delta_{as} \cdot f(\tau)$ is obtained.

Using this graph and determining the time required to lower the filtration column into the aquifer interval, the residual strength of the annular filter discs is established. It is important that the monolithic structure of the discs is maintained for a sufficiently short subsequent period before entering the productive formation. Let us consider the strength condition of the annular discs at this moment.

Assume that a filter of length (L) contains an equal number of annular gravel filter elements, with the bottom element in contact with a rigid support. One such section contains, for example, (K) annular elements. From this, it follows that the greatest compressive stress will be experienced by the bottom layer of the mentioned element.

Taking into account the weight of the annular gravel filter elements adjacent to the lower support 5, we determine their weight in water as

$$P_0 = (\gamma_g - \gamma_w)\frac{\pi}{4}(D_{outf}^2 - D_{\text{inf}}^2)HK, \qquad (2)$$

where γ_g, γ_w are the specific weights of gravel and water, respectively, N/m^3: D_{outf}, D_{inf} are the outer and inner diameters of the annular gravel discs, respectively; H is the height of one annular disc, m; K is the number of discs in the filter.

The compressive stress in the bottom annular disc, adjacent to support *5*, will be, taking into account (1)

$$\delta_{cs} = \frac{(\gamma_g - \gamma_w)\pi/4(D_{outf}^2 - D_{\text{inf}}^2)HK}{\pi/4(D_{outf}^2 - D_{\text{inf}}^2)} = (\gamma_g - \gamma_w)HK\ . \qquad (3)$$

The stress δ_{cs} must satisfy the compressive strength requirements of the gravel filter, with a value of t^*

$$\delta_{cs} = (\gamma_g - \gamma_w)HK < \sigma(t^*), \qquad (4)$$

where $\delta(t^*)$is the compressive strength of the filter at time t^* of exposure to water on the monolithic gravel discs, i.e., t^* is the time measured from the initial moment of lowering the filtration column to the placement of the filter in the aquifer interval.

To determine $\sigma\int(t^*)$ the strength graph of cubes made from the same gravel material should be used.

If the time t^* is exceeded, i.e., the strength of the annular discs weakens even further, formula (3) is no longer valid, and the disintegration products (gravel) fill the annular space, causing a reduction in the pack level. This negatively affects the operation of the water intake well, especially when there is a large difference between the aquifer opening diameter and the outer diameter D_{out} of the annular discs.

Let us determine the position of the gravel pack when filling the filtered space of the well (Fig. 3).

The initial volume (V) of the gravel pack in its monolithic state is equal to

$$V = \frac{\pi}{4}(D_{outf}^2 - D_{\text{inf}}^2)L. \qquad (5)$$

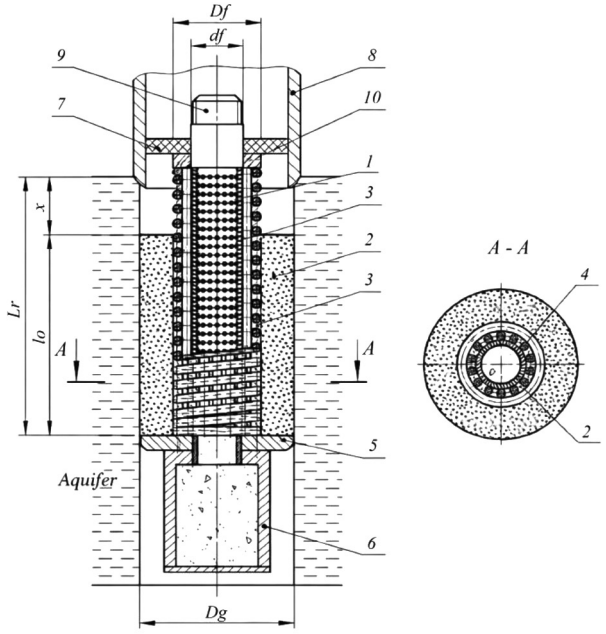

Fig. 3. Position of the filter's gravel bed during the disintegration of the ring discs:

1 – perforated frame; 2 – wire winding; 3 – loose gravel bed; 4 – steel rods; 5 – lower stop; 6 – sediment tank; 7 – oil seal; 8 – water lifting column; 9 – filter column; 10 – upper stop

During disintegration, the gravel pack fills the annular space. Its volume (V) does not change, but is determined by the modified formula

$$V = \frac{\pi}{4}(D_{outf}^2 - D_{\text{inf}}^2)(L - \Delta l), \qquad (6)$$

where Δl is the decrease in the gravel pack level when filling the annular space.

Equating (5 and 6)

$$\frac{\pi}{4}(D_{outf}^2 - D_{\text{inf}}^2)L = \frac{\pi}{4}(D_{outf}^2 - D_{\text{inf}}^2)(L - \Delta l). \qquad (7)$$

From relation (7), the magnitude of the gravel pack level reduction Δl in the annular space is determined.

$$\Delta l = (D_g^2 - D_{\text{inf}}^2) = (D_g^2 - D_{\text{inf}}^2)L - (D_{outf}^2 - D_{\text{inf}}^2)L, \qquad (8)$$

or

$$\Delta l = \frac{(D_g^2 - D_{outf}^2)L}{(D_g^2 - D_{\text{inf}}^2)}. \qquad (9)$$

From (8), it follows that the greater the filter length L and the difference between the borehole diameter D_g and the outer diameter of the annular discs, the greater the decrease in the gravel pack level Δl

Example: D_g = 190 mm = 0.19 m. D_{outf} = 180 mm = = 0.18 m; D_{inf} = 140 mm = 0.14 m L = 6 m.

We determine the value of the gravel pack level decrease Δl using formula (8)

$$\Delta l = \frac{0.19^2 - 0.18^2}{0.19^2 - 0.14^2} \cdot 6 = \frac{0.036 - 0.0324}{0.0361 - 0.196} \cdot 6 = \frac{0.0037}{0.0165} 6 = 1.35.$$

In work [23], recommendations are given to reduce the gap between the drilling diameter in the aquifer and the diameter of the gravel filter to a minimum value (1–2 mm). In our opinion, such recommendations are

rather questionable, especially when drilling deep wells or in complex geological conditions that cause well curvature. It is more reasonable to deliver the missing portion of gravel pack from the surface through the drill string via an adapter with inclined channels that direct the gravel directly into the annular filter zone surrounding the exposed wire-frame base of the filter.

Conclusions.

1. Based on a detailed analysis of the existing methods for constructing gravel packs of water intake well filters, the feasibility of applying cryogenic technology has been justified. The essence of this method lies in the preliminary formation of annular gravel elements on the surface, which are temporarily solidified using special binding substances. After lowering the filter into the aquifer interval and its contact with water, the temporary bonds gradually break down, resulting in the transformation of monolithic blocks into a loose, evenly distributed gravel pack. This approach significantly improves the uniformity of the filter zone, reduces the likelihood of void formation, and consequently increases the durability and efficiency of well operation.

2. A methodology has been developed for calculating the compressive strength of temporarily solidified annular gravel elements of the filter. The methodology is based on accounting for the changes in the strength characteristics of the material under the influence of filtrating water under actual well operating conditions. Unlike previously existing approaches, the new method makes it possible to predict the decrease in strength over time and to estimate the period during which the designed stability of the blocks is maintained. This allows for more accurate selection of filter parameters and operating modes, thereby increasing the overall reliability of the water intake system.

3. A mathematical dependence was developed to characterize the variation in gravel-pack elevation within the annular space caused by the degradation of the ring-shaped filter components. The analysis demonstrated that the magnitude of gravel settlement is primarily controlled by the annular clearance between the wellbore and the filter assembly, as well as by the length of the screened interval. These findings provide a basis for incorporating well geometry into filter design procedures, estimating gravel redistribution during operation, and assessing potential gravel losses, thereby improving the reliability of engineering calculations and design solutions.

4. To compensate for the decrease in the gravel pack level during operation, a technical solution has been proposed that provides the possibility of supplying an additional portion of gravel. For this purpose, it is recommended to use a drill string equipped with an adapter containing inclined channels that ensure uniform distribution of the material in the annular filter space. This method of gravel supply makes it possible to promptly restore the required gravel pack level, maintain stable filtration properties, and extend the service life of the well without the need for major repair operations.

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Створення кріогенно-гравійного фільтра необхідної міцності й компонування його загальної конструкції

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Мета. Основною метою дослідження є підвищення ефективності експлуатації водозабірних свердловин, обладнаних гравійними фільтрами, а саме збільшення обсягу й поліпшення якості води, що видобувається для потреб населення Республіки Казахстан.

Методика. У роботі проведено комплексний аналіз існуючих конструкцій гравійних фільтрів та особливостей їх роботи в умовах піщаних водоносних горизонтів. Для перевірки теоретичних положень виконані експериментальні випробування зразків гравійних елементів: вони випробовувалися на стиск як у сухому стані, так і після насичення водою. Додатково проведене аналітичне моделювання процесу зниження рівня гравійної обсипки у фільтрувальному просторі свердловини.

Результати. Розроблено розрахунковий підхід для оцінки міцності кільцевих гравійних елементів фільтра. Експериментально виявлені закономірності зниження міцності матеріалу у часі при контакті з водою. Встановлено, що зниження рівня обсипання визначається величиною зазору між обсадної колоною й фільтром, а також довжиною фільтруючої частини. Для компенсації втрат запропонована технологія подачі додаткового обсягу гравію через бурильну колону, що дозволяє відновити розрахунковий рівень обсипання.

Наукова новизна. Уперше запропонована методика динамічної оцінки міцності кріогенно-гравійних елементів з урахуванням процесів їх розмонолічування у водному середовищі. Отримані аналітичні залежності, що дозволяють прогнозувати зниження рівня гравійного обсипання в залежності від геометрії фільтра й параметрів свердловини. Розроблено нове технічне рішення, спрямоване на стабілізацію обсипання у процесі експлуатації.

Практична значимість. Отримані результати представляють інтерес для організацій, що займаються проєктуванням, бурінням й облаштуванням водозабірних свердловин. Застосування кріогенної технології сприяє більш рівномірному розподілу гравійного обсипання, знижує ризик втрати фільтраційних властивостей і забезпечує довговічність роботи свердловин.

Ключові слова: *гравійний фільтр, кріогенна технологія, гравійне обсипання, водозабірна свердловина, питне водопостачання*