INNOVATIVE TECHNOLOGIES FOR EQUIPPING OPERATIONAL WELLS WITH SYSTEMS FOR MECHANICAL PURIFICATION OF LIQUID AND GASEOUS MINERAL RESOURCES

Gulzada Umirova[1], Andrii Sudakov[2], Dmytro Pobidynskyi[2], Askar Seidaliyev[3]
[1]Kazakh National Technical University named after K.I. Satpayev, Kazakhstan;
[2]Dnipro University of Technology, Ukraine;
[3]Caspian University of Technology and Engineering named after Sh. Yessenov, Kazakhstan
zhangirxanova@list.ru

Abstract. The goal is to develop technologies intended for long-term equipping of operational wells of various purposes with systems for mechanical purification of liquid and gaseous mineral resources in productive horizons located at any depth, represented by medium-grained, fine-grained, silty, and dusty sands. The work uses methods of analyzing innovative technologies and materials, generalizing scientific and technical achievements in various fields of economic activity, as well as synthesis and physical modelling of systems for mechanical purification of liquid and gaseous mineral resources. The joint developments of the Kazakh National Research Technical University named after K.I. Satpayeva and the Dnipro University of Technology are presented, focusing on technologies for constructing systems for mechanical purification of liquid and gaseous mineral resources in productive horizons located at any depth, represented by medium-grained, fine-grained, silty, and dusty sands. For the first time, the use of water-based binding materials containing organic polymers for solidifying loose gravel material into a block structure of a gravel filter for mechanical purification systems of operational wells has been justified. For the first time, the possibility of equipping the intake part of hydrogeological wells in medium-grained, fine-grained, silty, and dusty sands with mechanical purification systems featuring removable casings and sealing systems has been substantiated. It lies in the development of: recommendations for selecting parameters of technologies for equipping hydrogeological wells with systems for mechanical purification of liquid mineral resources; at the level of inventions of fundamentally new technologies for equipping the productive part of wells with gravel filters, the implementation of which, compared to traditional technologies, reduced the cost of well equipment by 0.6 to 1.0 thousand USD for wells with a depth of up to 100 meters.

Keywords: Water supply, well, gravel filter, productive horizon.

Introduction

In drilling wells of various purposes – water, oil, gas, and in situ leaching – the movement of fluids occurs in direct (out of the well), reverse (into the well), and reversible directions (wells of underground gas storage facilities) [1; 2]. Throughout the entire operational period of the well, its walls within the productive formation must remain stable. This stability is typically achieved by installing filters in the well, which are designed to prevent wall collapse and to mechanically purify the fluids entering the intake section from solid impurities [3; 4].

Depending on the particle size of the productive formation rock, various types of filters have been developed. These range from the simplest designs, such as perforated tubular or frame-rod filters, to more complex constructions like gravel filters [5; 6]. Gravel filters are predominantly used in wells where the productive formation consists of sands. For medium-grained sands, a single-layer gravel pack is typically recommended, whereas for fine-grained sands, multilayer filters (two- or three-layer) are more suitable [7; 8].

This article provides a review of existing technological solutions for equipping operational wells with systems for mechanical purification of liquid and gaseous mineral resources. It discusses previously developed and implemented methods, with a focus on the application of innovative approaches aimed at improving the operational reliability and efficiency of wells completed in productive horizons composed of medium-grained, fine-grained, silty, and dusty sands.

Materials and methods

The study is based on a comprehensive analysis of innovative technologies and materials used for mechanical purification of liquid and gaseous mineral resources. The research methodology includes the generalization of scientific and technical achievements in the field of well completion, as well as a comparative analysis of the structural features, efficiency, and application conditions of different types of gravel filters.

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The analysis involved reviewing patents, scientific articles, and technical reports related to the design and application of gravel filters in hydrogeological wells. Special attention was given to filters used in productive horizons composed of medium-grained, fine-grained, silty, and dusty sands.

Physical modelling was conducted to evaluate the mechanical properties and operational characteristics of various gravel filter designs. Models were created to simulate the installation process, the integrity of the gravel pack during transportation and placement, and the behaviour of sealing systems under varying hydrodynamic loads. Additionally, the structural-genetic method was employed to classify and establish interrelationships among different gravel filter technologies.

Key evaluation parameters included:

- filter structural stability during installation,
- efficiency of mechanical purification,
- cost-effectiveness compared to traditional methods,
- ease of installation and operational reliability at depths up to 200 meters.

The technologies discussed in this article were compared based on these criteria to highlight potential advantages and limitations of each approach.

Results and discussion

Currently, there are two technologies for manufacturing gravel filters. In the first case, the filter is formed directly in the well [9; 10]. After lowering the filter column frame, loose gravel material is delivered into the well [11; 12]. In the second case, the gravel filter is pre-assembled on the surface and then lowered into the well in its final form [13; 14]. Both technologies have their advantages and disadvantages. However, a significant drawback of these methods is their complexity and the high cost of performing technological operations [15; 16].

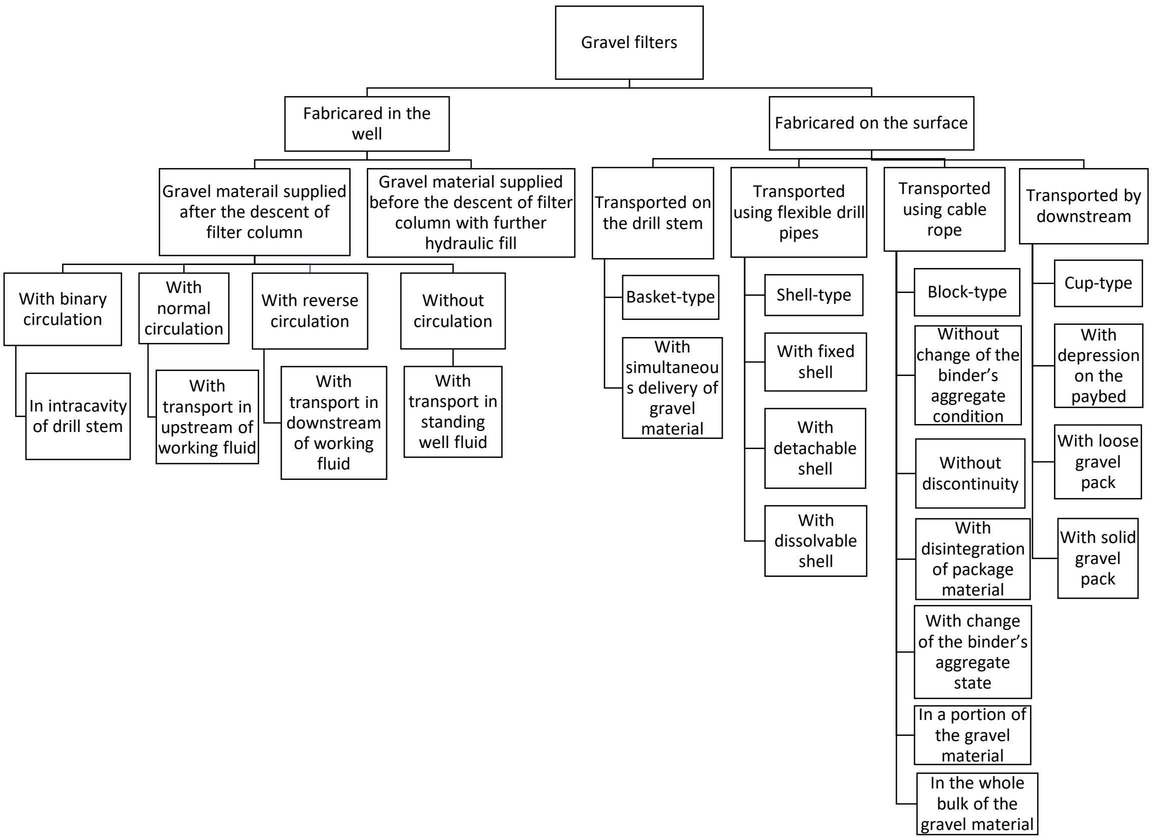

Fig. 1. **Classification of gravel filters of hydrogeological wells**

The use of the most distinctive features in analyzing gravel filter manufacturing technologies and their application in well completion has enabled the development of an improved classification (Fig. 1)

[17]. This classification includes not only the currently practiced methods of creating gravel packing in the intake section of wells but also methods that could potentially be implemented after appropriate modifications. The structural-genetic analysis applied to these methods has made it possible to establish relationships between them and to generalize them according to the main directions of gravel filter development.

The problem of drinking water is becoming increasingly critical worldwide. This is due to the fact that almost all freshwater sources have, to some extent, become contaminated by the byproducts of human activity.

The only solution is drilling hydrogeological wells. More than 60% of water wells are constructed in aquifers composed of loose sediments.

This major and relevant problem, which consists in developing technologies for the long-term outfitting of operational wells for various purposes with systems for mechanical purification of liquid and gaseous mineral resources in productive horizons at any depth, composed of medium-grained, fine-grained, silty, and dusty sands, and having significant practical importance, is the focus of the research conducted at the National Research Technical University named after K.I. Satpayev and the Dnipro University of Technology.

Casing gravel filters with a removable-extractable casing [18]. The distinctive feature of the technology for using gravel filters with a removable protective casing (Fig. 2) is their assembly on the surface. During this process, a gravel pack (which can be multilayered, if necessary) with specified physical properties is formed in the space between the filter column frame 9 and the removable protective casing 2 under visual control. After assembly, the gravel filter is transported down the wellbore to the bottom, where the removable casing is detached and subsequently extracted from the well to the surface using a drill pipe string.

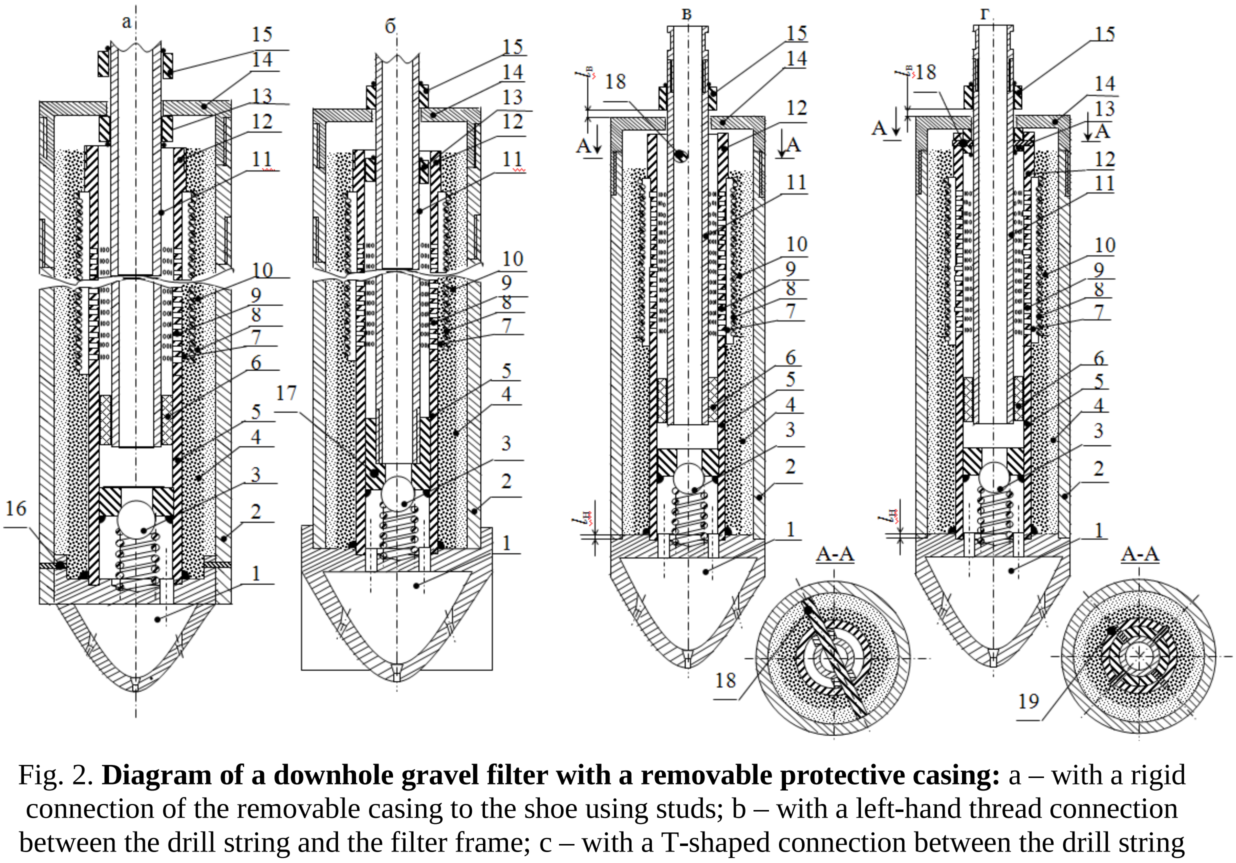

Fig. 2. **Diagram of a downhole gravel filter with a removable protective casing:** a – with a rigid connection of the removable casing to the shoe using studs; b – with a left-hand thread connection between the drill string and the filter frame; c – with a T-shaped connection between the drill string and the over-filter pipe; d – with a rigid connection of the drill string to the over-filter pipe using studs; 1 – shoe; 2 – removable casing; 3 – check valve; 4 – outer layer of gravel pack material; 5 – sediment trap; 6 – seal; 7 – spacer rods; 8 – wire wrapping; 9 – tubular frame of the filter column; 10 – inner layer of gravel pack; 11 – drill pipe string; 12 – over-filter pipes; 13 – support; 14 – casing cover; 15 – safety device

A distinctive feature of the developed and proposed gravel filters is that they include a removable protective casing 2, with a diameter as close as possible to that of the intake section of the well. The casing 2 is designed to form the gravel pack and prevent its integrity from being compromised until the filter is put into operation, as well as to center the gravel filter when installed in the aquifer, among other functions. Upon a detailed examination of gravel filter designs, only the filter with a rigid connection between the removable casing and the shoe using studs (Fig. 2a) can have a significantly long filter column. The assembly of the gravel filter and the extension of the filter column according to this scheme are carried out at the wellhead after the removable protective casing 2 is attached to the shoe 1 using shear studs 16. The filter is prevented from falling into the well at the wellhead by clamps secured to the removable protective casing 2. The other gravel filter designs (Fig. 2b, 2c, 2d) have limitations on the length of the filter column due to the height of the drilling rig mast. Additionally, in the cases shown in Fig. 2c and 2d, to prevent the protective casing 2 from lifting during the transportation of the gravel filter to the aquifer and to ensure the formation of a high-quality gravel pack in the aquifer, the following condition must be met during filter assembly and transport

$$l_{\text{н}} > l_v > l_c,$$

where $l_{\text{н}}$ – depth of the casing seat in its designated position within the sediment trap shoe;
l_v – free movement range of the casing, limited by the safety device;
l_c – slot size of the lock.

Transportation of the gravel filter is carried out using the drill pipe string 11, which, depending on the selected design, is connected to the filter through:

- shear studs 16, which rigidly connect the lower part of the removable casing 2 to the filter shoe 1, and a support 13, which is rigidly attached to the drill pipe string 11. The drill pipe string can move axially, with its movement limited by the support 13 and the safety device 15 (Fig. 2a);
- a coupling with a left-hand thread 17, rigidly installed inside the sediment trap 5, functionally integrated with the check valve (Fig. 2b);
- a T-shaped key 18, which secures the coaxial alignment of the filter column frame 9 with the body of the removable casing 2 (Fig. 2c);
- shear studs 19, structurally positioned in the support 13, which is rigidly fixed to the drill pipe string 11, and in the upper part of the over-filter column 12 of the gravel filter (Fig. 2d).

The placement of the gravel filter in the aquifer can be carried out:

- into an open aquifer with the designed diameter. In this case, the diameter of the removable casing should be as close as possible to the diameter of the intake section of the well;
- into a pilot well of a smaller diameter, where its placement is carried out by expanding the intake section through hydraulic jetting using technical water;
- by the method of simultaneous aquifer penetration and gravel filter placement through hydraulic jetting.

After the filter is set at the designed depth (Fig. 2a, 2d), the axial load created by the weight of the drill pipe string causes the shear studs to break, followed by the extraction of the removable protective casing 2 from the well, exposing the gravel pack material.

Sleeve gravel filter [19]. The above-described technologies and designs of gravel filters, despite their advantages over traditional methods, have certain drawbacks, one of which is the labor-intensive process of manufacturing and equipping the intake section of a drilling well with a gravel filter. To eliminate this drawback, the authors propose the use of sleeve technology under industrial conditions for equipping the intake section of drilling wells. The schematic diagram of well equipment is shown in Fig. 3.

The stated problem is solved by the fact that the gravel filter, containing gravel material, an over-filter column, working zone, and a sediment trap, is distinguished by having: an elastic sleeve positioned above the gravel; an elastic sleeve secured to the sediment trap; a widened-contour sediment trap with a sleeve fixed at its upper part; a check valve inside the sediment trap; an additional elastic sleeve secured above the gravel material.

The frame of the filter column contains a widened-contour sediment trap 1 in its lower part. The upper part of the widened-contour sediment trap 1 is connected to the working section of the filter column 4, to which spacer rods 5 are attached. A wire winding 6 is wrapped around their outer surface under workshop conditions, with selective fixation. In the lower part, a sleeve 2, made in a cup-shaped form from canvas, is secured to the filter column 4 using a clamp 3. Its diameter in the working position should exceed the internal diameter of the production casing by 50-100 mm.

At the upper part of the filter column 4, there is an over-filter column 7. When installing the filter “flush-mounted”, the length of the over-filter pipe should be such that its upper part is positioned at least 3 meters above the shoe of the casing string for wells up to 30 meters deep and at least 5 meters for deeper wells. The transportation of the gravel filter is carried out using the drill pipe string. The placement of the gravel filter is performed into an open aquifer with the designed diameter.

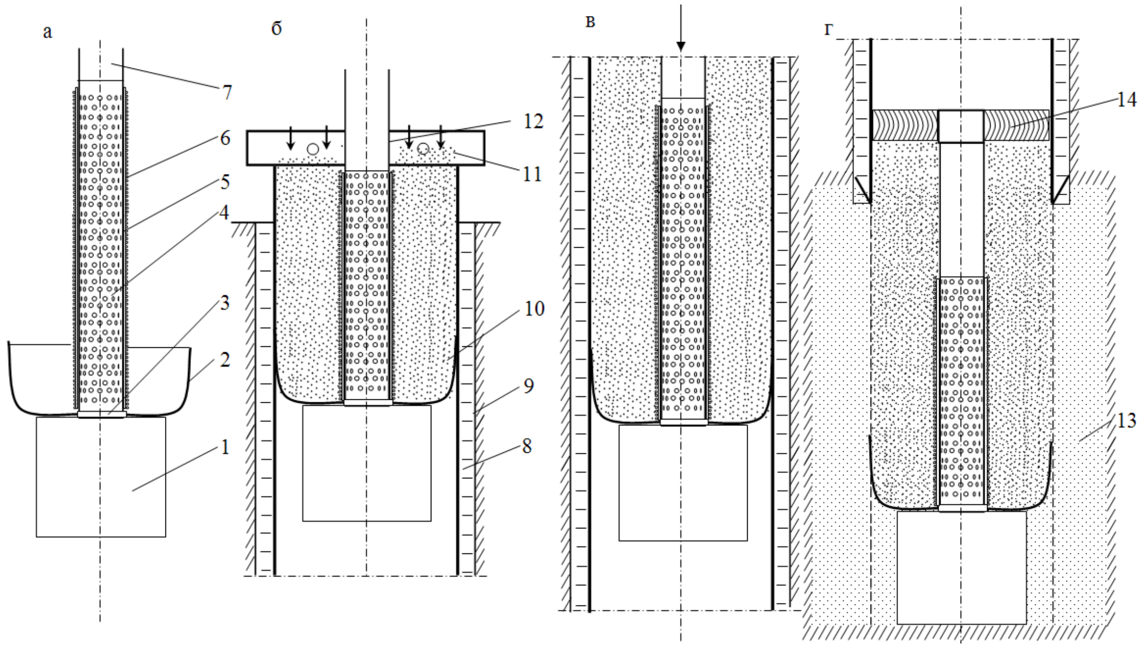

Fig. 3. **Diagram of the technology for equipping the intake section of a well with a gravel filter:** a – assembled filter column; b – formation of the gravel filter at the wellhead; c – transportation of the gravel filter through the wellbore; d – gravel filter in operational state; 1 – widened-contour sediment trap; 2 – sleeve; 3 – sleeve clamp; 4 – working section of the filter column; 5 – spacer rods; 6 – wire winding; 7 – over-filter column; 8 – cement stone; 9 – production casing; 10 – gravel pack of the filter; 11 – clamp; 12 – filter column coupling; 13 – aquifer rock; 14 – seal

Block gravel filters

Cryogenic-gravel filter (CGF) [17]. The concept is based on developing a technology for manufacturing a block-structured gravel filter element by binding gravel material into a monolithic composite using a water-based binder. This element is then delivered and installed in the well in a single portion, transitioning from a monolithic state to a loose form as the mineral binder acquires the rheological properties of water under the influence of thermal fields from well and formation waters.

The production of the cryogenic-gravel filter (CGF) can follow two technologies. To implement the first technology, the following technological operations must be performed (Fig. 4): manufacturing the cryogenic-gravel element (CGE) of the block-structured filter on the surface; assembling the working section of CGF, consisting of cryogenic-gravel sections (CGS) made from CGE; transporting CGF through the wellbore to the productive horizon; setting CGF in the intake section of the well. The CGE is manufactured using natural or artificial cold (in a refrigeration unit).

After assembly in the transport position, CGF (Fig. 4a), consisting of CGS, is transported through the wellbore to the intake section of the well, followed by its installation in the productive horizon. CGF is activated and brought into working condition under the influence of positive temperatures and the excess pressures of formation waters.

The results of this work have been practically applied in Ukraine for equipping hydrogeological wells under the conditions of commercial enterprises BK "Azovnerudgeologia" and LLC Industrial-Geological Group "Dneprogidrostroy".

Additionally, the cryogenic-gravel filter (CGF) technology introduces the use of a cryogenic binder, which enables the gravel material to transition from a solid to a loose state after installation.

The structural design and installation process are illustrated in Figure 4, where:

- Figure 4a shows CGF in its initial (transport and assembly) state, with cryogenic-gravel elements (CGE) enclosed within a support structure.
- Figure 4b presents CGF in its operational state, after placement in the intake section of the well. At this stage, the cryogenic binder dissolves under the influence of elevated formation temperatures and pressure, allowing the gravel material to form a porous and functional filtration layer.

The diagram in Figure 4b also demonstrates the interaction between key gravel filter components and the well geometry, including the sealing mechanism (element 10), the sediment trap (1), and the contact zones with surrounding aquifer rocks (2, 3). This configuration ensures precise positioning of the filter, minimizes fluid bypass, and enhances structural stability under hydrodynamic loads.

According to the second technology, CGF is manufactured directly on the filter column, transported through the wellbore to the productive horizon, and set in the intake section of the well. The production of CGF on the filter column is carried out using a refrigerant, such as liquid nitrogen (Fig. 5). The results of this work have been practically applied in Ukraine for equipping hydrogeological wells under the conditions of the commercial enterprise BK "Odesaburvod".

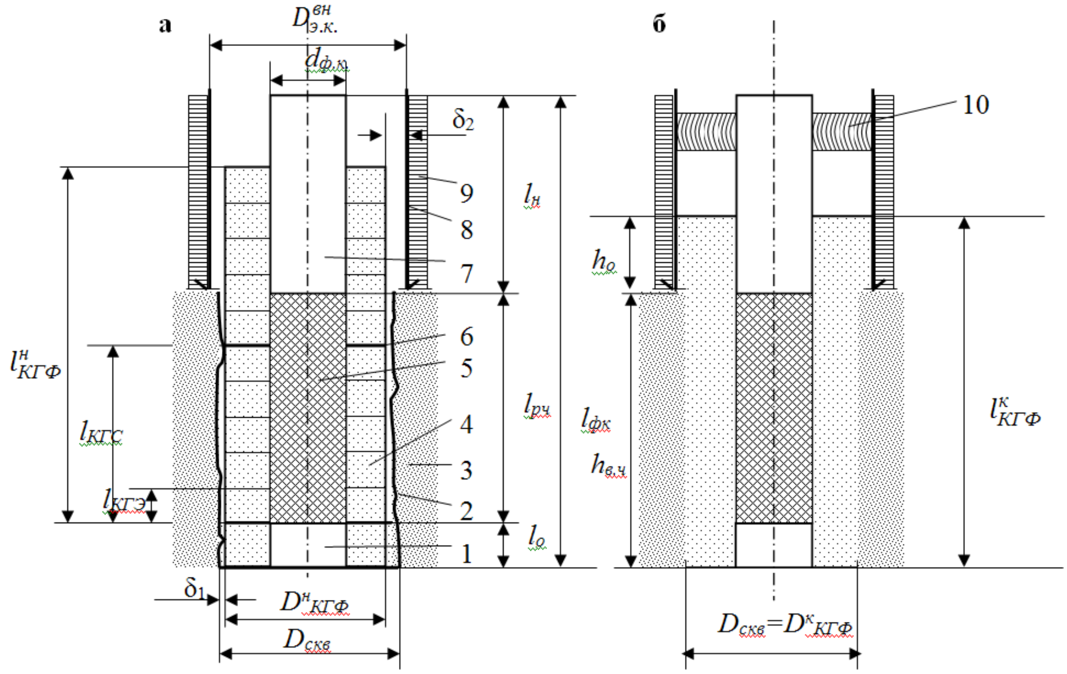

Fig. 4. **Diagram of CGF installation in the intake section of the well:** a – CGF in its initial state; b – CGF in operational state; 1 – sediment trap; 2 – walls of the intake section of the well; 3 – rock of the intake section of the well; 4 – cryogenic-gravel element (CGE); 5 – working section of the filter; 6 – support element; 7 – over-filter pipe; 8 – production casing; 9 – cement; 10 – seal

Polymer-gravel filter (PGF) [20]. The idea is based on using a fundamentally new additive to the binder of the gravel pack and a technology for manufacturing a block-structured gravel filter. These prevent premature structural degradation and ensure the integrity of the gravel pack during assembly, lowering the filter through the wellbore, and placing it in the productive horizon, followed by its dissolution and transition of the gravel material from a monolithic to a loose state. The technical result is achieved by designing a gravel filter (Fig. 4) that includes gravel material, a binding material, and a filter column frame. The distinguishing feature is the use of polymer water solutions as the gravel-binding material, which undergo thermal treatment at temperatures ranging from 30 to 3000°C.

Fig. 5. **Production of CGF using nitrogen with subsequent installation in the intake section of the well**

The filter is constructed on the surface in a waterproof container that replicates the contours and external radial dimensions of the gravel filter, the filter column frame, and the aquifer. This allows for the formation of a high-quality gravel layer around the filter frame with specified parameters under constant visual control. For this purpose, a prepared homogeneous gravel material is mixed with an aqueous polymer solution, followed by thorough mixing. The resulting viscous-plastic composite is poured into waterproof containers (molds), where dynamic impact ensures the formation of a uniform, homogeneous gravel block with the required dimensions. The monolithization of the composite is achieved through subsequent drying at a temperature of 30…3000 °C, resulting in a block-structured gravel filter with the necessary strength characteristics.

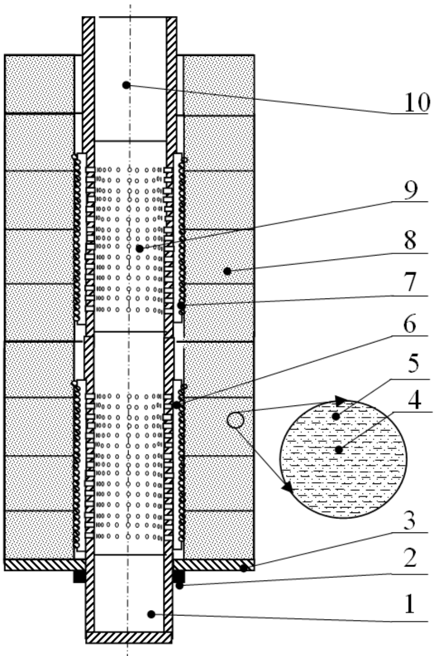

Fig. 6. **Diagram of the polymer-gravel filter:** 1 – sediment trap; 2 – support element; 3 – clamp; 4 – gravel pack material; 5 – mineral-binding material; 6 – spacer rods; 7 – wire winding; 8 – ceramic-gravel block; 9 – tubular filter frame; 10 – over-filter pipe

After assembly, lowering the filter through the wellbore and placing it in the productive horizon, the polymer dissolves under the influence of formation fluid (well fluid), thereby bringing the gravel pack into its working loose state, while the binder itself is washed out.

The discussed technologies for applying gravel filters are designed for complex geological and technical conditions of well construction and operation. The proposed technologies are applicable for equipping drilling wells of various purposes in the interval of productive horizons composed of medium-grained, fine-grained, silty, and dusty sands, with depths of up to 200 meters.

The comparative evaluation of proposed filter designs revealed that the use of pre-assembled removable casing systems and cryogenic-polymer technologies led to a reduction in installation time by 25-30%, and a decrease in material losses by up to 40% compared to traditional in-well gravel pack techniques.

According to test modelling and engineering estimates, the implementation of polymer-gravel filters and CGF systems allowed for a cost reduction of approximately 600-1000 USD per well with a depth of up to 100 meters. Additionally, operational data from pilot wells showed an increase in the filter service life by 1.5-2 times and a 30-50% improvement in flow capacity due to enhanced gravel pack integrity and reduced clogging.

These results demonstrate the practical advantages and technical feasibility of applying innovative filtration technologies in wells developed in unconsolidated sand formations.

Conclusions and recommendations

This study systematizes and evaluates innovative technologies for equipping operational wells with mechanical purification systems, especially under complex hydrogeological and operational conditions. The analysis focused on productive horizons composed of medium-grained, fine-grained, silty, and dusty sands at depths up to 200 meters.

The key scientific contribution of this research lies in the integration and justification of advanced filtration systems that employ removable protective casings, elastic sealing elements, and cryogenic or polymer-based binders. These solutions enable surface assembly under controlled conditions and simplify well completion procedures.

According to comparative and experimental results, the implementation of these systems results in:

- reducing equipment costs by approximately 600-1000 USD per well (depths up to 100 meters),
- decreasing the installation time by 25-30%,
- reducing material losses during filter packing by up to 40%,
- improving the filter flow capacity by 30-50% due to enhanced gravel structure uniformity,
- extending the service life of the filtration system by 1.5-2 times.

Moreover, these technologies help minimize the ingress of foreign particles into the gravel pack before well development, which directly affects hydraulic resistance and filtration quality.

These results confirm the novelty and practical significance of the proposed technologies and justify their implementation in both hydrogeological and production wells. Their application supports improved technical reliability, cost-efficiency, and compliance with sanitary and environmental standards.

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Author contributions

Gulzada Umirova – project administration, problem statement; Andrii Sudakov – design development and justification, editing; Askar Seidaliyev, Dmytro Pobidynskyi – patent research, editing, visualization of results.

All authors have read and agreed to the published version of the manuscript.

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