SELECTION AND JUSTIFICATION OF BINDING MATERIAL FOR POLYMER-GRAVEL COMPOSITE OF BLOCK TYPE INVERSE GRAVEL FILTER

Gulzada Umirova[1], **Andrii Sudakov**[2], **Aidar Kuttybayev**[1], **Diana Sudakova**[2]
[1]Kazakh National Technical University named after K.I. Satpayev, Kazakhstan;
[2]Dnipro University of Technology, Ukraine
a.kuttybayev@satbayev.university

Abstract. The aim of the work is to justify the possibility of using organic polymers as a binding material for a positive temperature technology designed for long-term equipment of operational wells of various purposes with systems for mechanical purification of liquid and gaseous mineral resources in productive horizons located at depths greater than 200 m, represented by medium-grained, fine-grained, silty, and dusty sands. The work utilizes methods of analysis of innovative technologies and materials, synthesis and research of materials, as well as the development of systems for mechanical purification of liquid mineral resources, along with the generalization of scientific and technical information. The selection of the binding material for the polymer-gravel composite of the inverse gravel filter of the block type has been justified, as well as the technology for its use in systems for the mechanical purification of liquid and gaseous mineral resources, intended for the equipment of productive horizons. For the first time, the use of water-based binding materials containing organic polymers for solidification of loose gravel material into a block structure of a gravel filter for mechanical purification systems of operational wells has been justified, according to the proposed technology. For the first time, the dependence of the physical-mechanical properties of the polymer-gravel composite on the mass concentration of the binding material has been established. It lies in the development of a program and conducting studies on the physical-mechanical properties of the polymer-gravel composite filter, and based on this, the development of well-founded recommendations for determining the parameters of technologies for manufacturing systems for mechanical purification of mineral resources and equipping hydrogeological wells with them.

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

Introduction

Ensuring the provision of high-quality drinking water to the population is a priority not only for the Republic of Kazakhstan and Ukraine but for the entire world. The UN General Assembly has recognized the shortage of drinking water as an urgent issue [1; 2].

In the context of anticipated unfavorable environmental and climatic changes, as well as insufficient water supply in technogenically loaded areas of the Republic of Kazakhstan, organizing drinking and technical water supply becomes a top priority for local authorities.

In the future, the development of the mentioned areas is expected to result in a multiple increase in water demand. Since 2002, several programs have been consistently implemented in the country (“Drinking Water”, “Ak-Bulak”, State Program for Regional Development), which in particular include the construction of thousands of hydrogeological wells to address the water supply issues in the problematic regions [3; 4]. However, without hydrogeological justification for the location and construction of hydrogeological wells equipped with modern well water purification systems, this problem will remain unresolved.

The quality of the constructed wells and their operational characteristics are largely determined by the set of works carried out at the final stage of construction, which includes the exposure of the aquifer, installation of a filter, and development of the aquifer.

Particular difficulty arises with issues related to the exposure and equipping of the water intake part of the well with gravel filters, where the aquifers are represented by medium-grained, fine-grained, very fine-grained, and silty sands [5; 6].

Many researchers have focused on improving the quality of gravel packings [7; 8]. Currently, there is no reliable technology for creating a gravel filter with high-quality gravel packing. The technologies for their creation have a number of drawbacks:

- significant time costs for transporting gravel material from the surface to the aquifer zone [8; 9];
- high-quality formation of the gravel pack requires complex surface and bottom-hole equipment and tools, which increase the cost of the work [10];

- stratification of gravel material by size, both in height and diameter, of the created gravel pack [11];
- suspension of gravel material during transportation, leading to the formation of blockages that require additional time and effort to eliminate [12];
- formation of voids in the gravel pack in the aquifer zone, which leads to sand ingress into the well [13; 14].

The use of block and casing filters also has several significant drawbacks. Casing filters have increased hydraulic resistance. During operation, casing filters are prone to rapid clogging due to electrochemical reactions. During lowering, they deform, which leads to the formation of an uneven gravel layer thickness and the creation of open channels and voids.

Recently, hydrogeological wells intended for public water supply from public wells have been equipped with block filters [15; 16]. Block filters are sensitive to impact loads, which can cause the destruction of the block structure (Fig. 1). In addition, block filters have lower permeability (Fig. 2) and higher hydraulic resistance [17; 18]. The effective porosity of the gravel layer is reduced either by the complete blocking of a number of filtration channels with adhesive or by their narrowing. Furthermore, in block filters adhesives are used as binders, which do not meet the sanitary standards and regulations for drinking water wells.

The aim of the work is to justify the possibility of using organic polymers as a binder in a positive-temperature technology intended for the long-term operation of wells of various purposes, equipped with systems for mechanical cleaning of liquid and gaseous mineral resources, in productive horizons located at depths greater than 200 m, represented by medium-grained, fine-grained, very fine-grained, and silty sands.

Materials and methods

The justification and selection of a mineral binder when applying cryogenic technology for cementing block filters is one of its most important elements.

The binder must meet the following requirements:

- be inert with respect to the gravel packing material of the filter;
- be strong during freezing, as well as during transportation and assembly of the filter at the drilling site;
- during transportation through the wellbore, it should not interact and be inert with respect to the well fluid;
- under prolonged hydrodynamic influence and increased ambient temperature, it should acquire rheological properties similar to water;
- be environmentally friendly;
- be non-deficient and have low cost.

In drilling practice, structuring additives widely used include hydrophobic substances such as cements, gypsum; polymers like hypan, starch, polyacrylamide, CMC, SSB, KSSB, sodium silicate, and others [19-21]. It is known that hydrophobic substances, when hydrated in a gravel composite, form dead-end pores, which results in a very low effective porosity of such block filters. When polymers are used in a block gravel filter at concentrations of 1-5% or higher, they form a hard-to-destroy, strong gel or jelly. As a result, such a block filter has low effective porosity. Sulfate liquor, alum, and calcium chloride are aggressive and toxic (alum contains arsenic and heavy metals). Tylose, agar, alginic acid, pectin, and protopectin have high costs [22; 23]. Moreover, during laboratory studies conducted by the authors, it was found that polymers such as starch, agar, and pectin degrade after exposure to low temperatures [24].

An analysis of the binders used allows for their classification into three groups (Fig. 1).

The classification of binding materials presented in Fig. 1 is based on the processes through which the gravel block is formed: hydration, polymerization, or phase transition. The classification includes materials that are currently used, as well as materials that have not been used as binding agents for gravel filters but may be applicable after further research.

In our opinion, gelatin most fully meets the above requirements.

Gelatin [26-30] is a product of collagen processing, a protein substance widely found in nature, which forms the main component of connective tissue, especially in the skin, ossein of bones, and tendons. The primary raw materials for gelatin production are the bones of cattle, waste from the leather industry (skin trimmings, hides), and tendons [31]. Recently, in Japan waste from whaling, which also contains collagen, and seaweed have been used for this purpose.

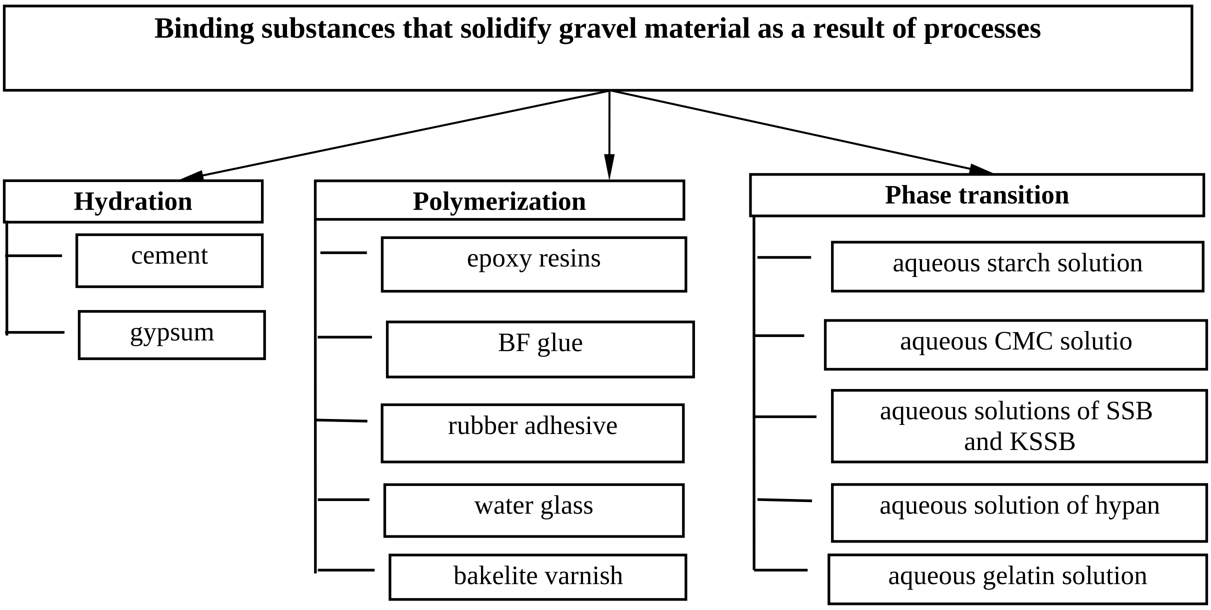

Fig. 1. **Classification of binding materials for block gravel filters [25]**

Depending on its properties and intended use, gelatin is classified into the following types [32]:

- food-grade – grades: K-13, K-11, K-10, P-11, P-9, P-7;
- technical-grade – grades: T-11, T-9, T-7, T-4, and T-2.5.

Depending on the degree of purity and quality, gelatin is classified into photographic, food, and technical grades.

Food-grade gelatin is intended for retail trade and for use in the food industry, including in the confectionery industry, for the production of meat and fish preserves, jelly, wine, ice cream, for preparing aspic dishes, mousses, creams, cakes, confectionery, and other products. Technical-grade gelatin is intended for use in the printing and light industries for the production of securities, photographic paper, fabric treatment, and other needs of the national economy. Gelatin is also used in medicine as a hemostatic agent and as a nutrient medium for cultivating bacteria. Gelatin is manufactured in accordance with the standard [32; 33], with adherence to sanitary regulations for gelatin industry enterprises, as approved by the relevant authorities. Food-grade gelatin, in terms of sanitary and hygienic indicators, must meet the requirements specified in Table 1.

Table 1

Sanitary and hygienic parameters of gelatin

Indicators	**Standard for food-grade gelatin**
Sulfurous acid, expressed as SO_2, %, not more than	0.075
Mesophilic aerobic and facultative anaerobic microorganisms, CFU, per 1 g of gelatin, not more than	$1 \cdot 10^5$
Coliform bacteria in 0.01 g of gelatin	Not allowed
Pathogenic microorganisms, including Salmonella, in 25 g.	Not allowed
Gelatin liquefying bacteria, CFU, per 1 g of gelatin, not more than	$2 \cdot 10^2$

The content of heavy metals and arsenic in food-grade gelatin does not exceed the standards. In terms of amino acid and elemental composition, gelatin is similar to collagen. The main components are: glycine (27%), proline (16%), hydroxyproline (14%), glutamic acid (12%), arginine (9%), and lysine (5%). The best grades of gelatin are lightly yellow in color. Due to the presence of acidic (carboxyl) and basic (amino) groups, gelatin has an amphoteric nature. Gelatin obtained by the “alkaline” method has an isoelectric point at pH 4.8-5.1, while gelatin obtained by the “acidic” method has an isoelectric point at pH 9. Gelatin swells in water and dissolves upon heating. When the aqueous solution cools, gelatin forms a jelly (gel), which, when heated, acquires the rheological properties of water. The gelation temperature and the strength of the gel depend on the gelatin concentration in the aqueous solution and the quality of the gelatin.

According to organoleptic and physicochemical indicators, gelatin must meet the requirements specified in Table 2.

Table 2

Physicochemical properties of gelatin

Name of the indicator	**Characteristics and standards for gelatin grades**										
	food						**technical**				
	К-13	**К-11**	**К-10**	**Р-11**	**Р-9**	**Р-7**	**Т-11**	**Т-9**	**Т-7**	**Т-4**	**Т-2.5**
Appearance	Granules, grains, flakes, powder						Granules, grains, flakes, powder, flakes, scales				
Color	From light yellow to yellow						From light yellow to light brown				
Smell	Free from foreign						Not regulated				
Taste	Freshwater						Not regulated				
Particle size, mm, not more than	5.0			10.0			10.0				
Mass fraction of fine particles, %, not more than	30.0						48.0				
Dissolution time, min, not more than	25.0						Not regulated				
Hydrogen ion activity of a 1% aqueous gelatin solution, pH units	From 5.0 to 7.0										
Moisture content, %, not more than	16.0										
Ash content, %, not more than	2.0						1.5			2.5	3.0
Gel strength of a 10% gelatin solution, N, not less than	13.0	11.0	10.0	11.0	9.0	7.0	11.0	9.0	7.0	4.0	2.5
Dynamic viscosity of a 10% gelatin solution, mPa·s, not less than	21.5	20.5	18.5	20.0	17.4	14.4	15.4	13.3	12.3	9.2	8.2
Melting temperature of a 10% gelatin gel, °C, not less than	32.0	32.0	30.0	32.0	30.0	27.0	31.0	30.0	29.0	26.0	23.0
Transparency of a 5% gelatin solution, %, not less than	50.0			45.0	35.0	25.0	40.0	30.0	20.0	Not regulated	
Foreign impurities, %, not more than	Not allowed						0.1				

The main quality criteria for gelatin are the viscosity of the solution, the strength of the jelly, the melting temperature, and the gelling temperature, measured under specific conditions. In concentrated solutions, some substances (such as potassium thiocyanate, sodium benzene sulfonate, etc.) dissolve gelatin in cold. These substances also hinder the formation of jelly. Under the action of tanning agents, gelatin loses its ability to swell in water and dissolve. Gelatin obtained from fish waste produces a weak jelly and is used only as glue.

Since gelatin has long been used in various industries, its properties are well known, and therefore, the study of the thermophysical properties of the composite was conducted based on literature sources. The analysis of the literature allowed us to determine the thermophysical parameters of the components of the composite and conclude that there are only minor changes in their properties when gelatin is introduced as a binding agent in amounts ranging from 1% to 15% by the weight of the liquid [34]. Gelatin is considered a difficult-to-burn substance. The ignition temperature of gelatin is 235 °C, and the self-ignition temperature is 310 °C (it smolders). When exposed to an open flame, gelatin chars. Gelatin is not explosive.

The object of the study is to establish the patterns of changes in the rheological properties of an aqueous solution of an organic polymer based on gelatin.

The study determined: the change in the density of the aqueous solution as a function of the mass concentration of gelatin in it; the change in the relative viscosity of the gelatin aqueous solution as a function of the mass concentration of gelatin and the ambient temperature.

Standard methods and equipment were used to determine the rheological properties. In the course of the research, food-grade gelatin of grade P-11 was used.

The gelatin was suitable for use and did not require preliminary preparation. The preparation of gelatin as a binding agent was carried out in the following sequence.

1. Weighing the gelatin in the required amount to prepare the polymer aqueous solution of the desired concentration;
2. Weighing the water in the required amount to prepare the polymer aqueous solution of the desired concentration.
3. The gelatin was poured into a container and covered with part of the water at room temperature.
4. For 40 minutes, the gelatin was allowed to partially dissolve and swell in the water until it reached a jelly-like consistency.
5. The second part of the water was heated to boiling temperature and poured into the container with the jelly, followed by stirring until a homogeneous solution was obtained. After preparing the aqueous gelatin solution, it was cooled to the required temperature, and then the rheological properties were determined.

Results and discussion

After performing the operations to prepare the binding agent, studies of its properties were conducted. The results of the studies are presented in Figures 2–6.

Figure 2 shows the dependence of the change in the density of the gelatin aqueous solution on its concentration. As a result of the study of the density properties, it was established that introduction of a small amount of gelatin (up to 5%) into the dispersion medium does not cause a change in the density of the solution. An increase in the density is observed in the aqueous polymer solution with a mass concentration of gelatin greater than 5%. For example, at a mass concentration of 10% gelatin, the density was 1010 $kg \cdot m^{-3}$, and when the concentration was increased to 15%, the density became 1020 $kg \cdot m^{-3}$.

The influence of the temperature of the gelatin aqueous solution on its density properties has not been established.

The results of the study of the rheological properties of aqueous solutions with different mass concentrations of gelatin are shown in Figures 3.2-3.5.

During long-term observations of the solution viscosity, it was noted that it begins to increase when the temperature reaches below 40°C, while the ambient temperature was 20 °C.

Figure 3 shows that at the initial temperature of the aqueous solutions of 43 °C, they cooled down gradually, and after 1 hour, their temperature dropped to 33 °C, and after 2 hours from the start of the experiment, it reached 24 °C (Figure 4). At the same time, the rheological properties of aqueous solutions containing more than 5% gelatin significantly increased. This occurs at temperatures below 33 °C.

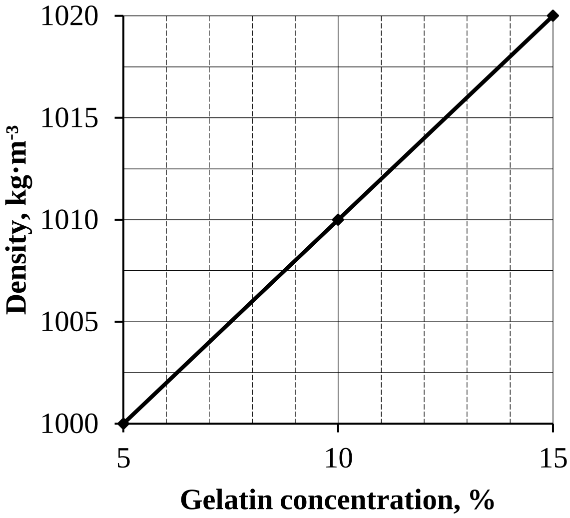

Fig. 2. **Dependence of the density of the aqueous solution on the gelatin concentration**

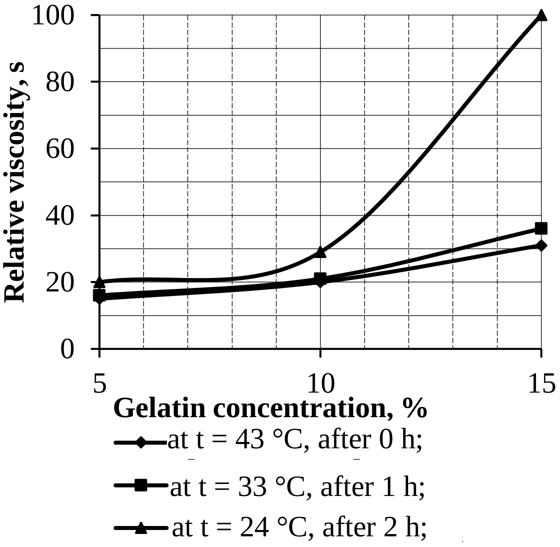

Fig. 3. **Dependence of the relative viscosity of the gelatin aqueous solution on the concentration and time after preparation**

This is especially noticeable in the aqueous solution with a 15% mass concentration of gelatin, which initially has a relatively high relative viscosity, 2.5 times higher than the viscosity of technical water, 2 times higher than the viscosity of a 5% gelatin aqueous solution, and 1.5 times higher than that of a 10% solution. Moreover, during cooling, after 2 hours below 33 °C, the relative viscosity increases by more than 2.5 times, and as seen in Figures 3,4, it reaches the state of 'non-flowing', i.e. the gel state.

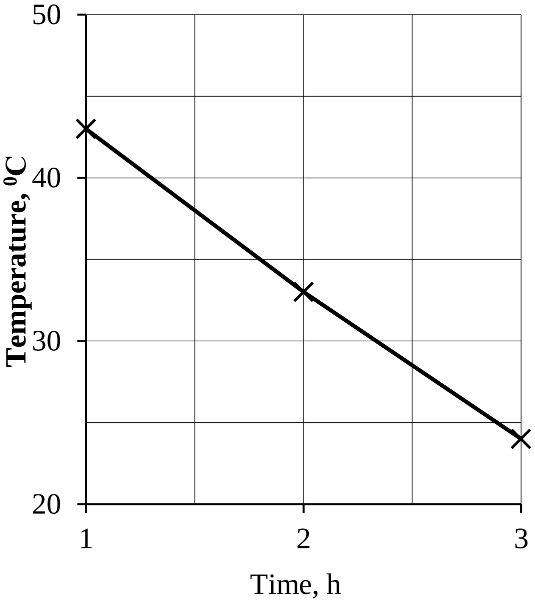

Fig. 4. **Dependence of the temperature of the gelatin aqueous solution on the time after preparation**

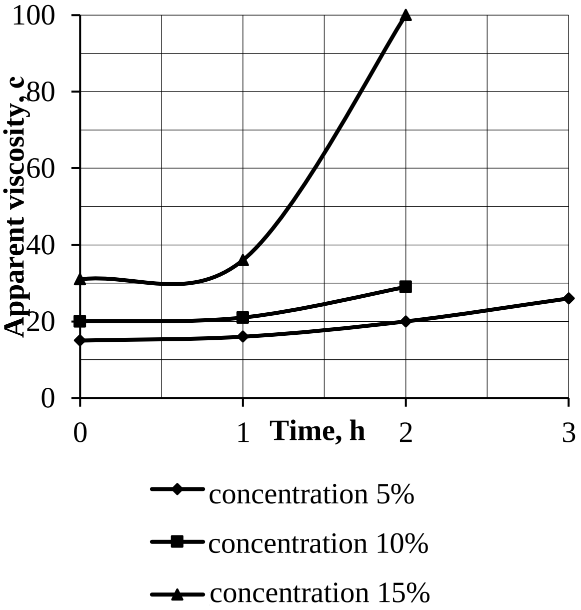

Fig. 5. **Dependence of the apparent viscosity of the gelatin aqueous solution on the time after preparation**

A similar situation occurs with the aqueous solution with a 10% mass concentration of gelatin. Its initial relative viscosity is 20 s, but as it cools, its viscosity also increases to the ‘non-flowing’ state, although this happens at a lower temperature of 24 °C.

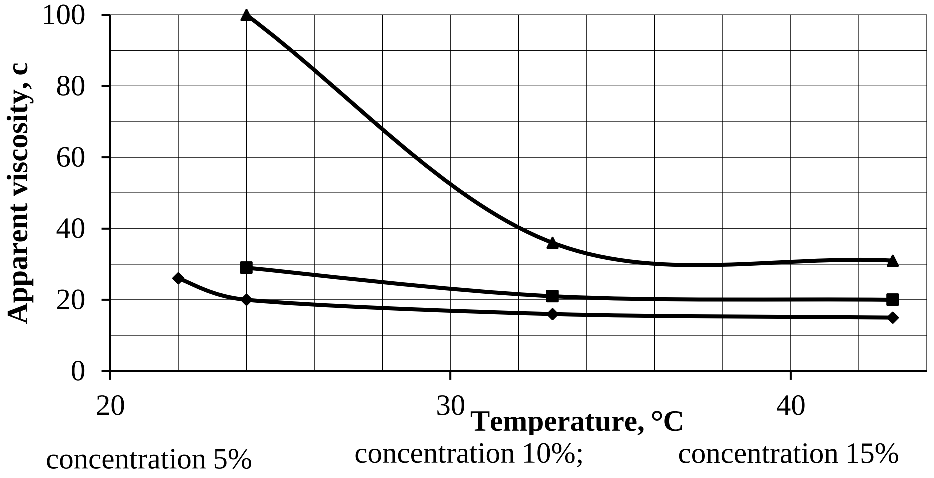

Fig. 6. **Dependence of the apparent viscosity of the gelatin aqueous solution on temperature**

From the perspective of technological properties, the use of an aqueous solution with a 5% mass concentration of gelatin is preferable, as its relative viscosity is close to that of technical water, being 17 s at 43 °C and 20 s when the temperature decreases to 24 °C.

In general, based on the obtained results, it can be concluded:

- the use of gelatin aqueous solutions as a binding agent is possible;
- the process of mixing the components of the GKC filter should be carried out at a temperature of the gelatin aqueous solutions not lower than 33 °C, as irreversible gelling processes occur when the temperature decreases.

Conclusions and recommendations

A formulation for the binding polymer-gravel composite of a block-type gravel filter has been developed and justified. The binder is an organic polymer based on water. Food-grade gelatin of grade T-11 has been proposed as the organic polymer.

Experimental studies have established the rheological properties of the food-grade gelatin aqueous solution of grade T-11. The possibility of its use as a binding substance for the polymer-gravel element of the filter has been demonstrated. The temperature limit for its mixing with the filter gravel has been established, which is 32°C.

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Author contributions

Gulzada Umirova - project administration, task formulation; Andrii Sudakov – development of the program and research methodology, editing; Aidar Kuttybayev, Diana Sudakova – justification of the binder, conducting research, visualization of results.

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

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