UDC 628.16 DOI: 10.31650/2786-6696-2025-11-115-122

VALIDATION OF POROUS CONSTRUCTIONS OF FILTER STRUCTURES

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Abstract. Rapid filters are important in technological schemes for purifying natural waters. They provide the required water quality, useful capacity of water treatment plants, as well as required technical and economic value. One of the main structural elements of filters is the wash water drainage system.

The authors outlined the basic requirements for diverter systems, namely, uniform collection of wash water from the filter area and prevention of entrainment of the filter medium during washing. The article discusses two design options that fully meet these requirements: horizontal gutters with inclined meshes on their upper edges and porous polymer concrete pipes. The article provides data indicating that inclined grids and porous polymer concrete prevent grains of filter medium with a size of 0.5 mm from penetrating. Such medium is most commonly encountered in filtration structures of domestic drinking water supply systems.

An experimental comparison of porous and mesh devices in systems for removing wash water from rapid filters was carried out by comparing their relative coefficients of hydraulic resistance.

It has been established that the coefficients of hydraulic resistance of polymer concrete and mesh initially increase with further stabilization. At the same time, their maximum relative values differ significantly from each other: coefficients of hydraulic resistance for polymer concrete $\overline{C}$ = 5.4; for mesh $\overline{\xi_c}$ = 2110.

The result of the conducted experiments shows that the head loss in polymer concrete during filtration under conditions of suspended medium is approximately four times lower than in the mesh due to the clogging of mesh cells with sand particles, confirming the advantages of porous polymer concrete.

Keywords: porous structures, mesh devices; rapid filter, hydraulic resistance coefficient.

Introduction. Mesh and porous structures are widely used in water supply facilities. Water intake and treatment facilities are the main elements in the water supply system, ensuring the reliability and cost-effectiveness of systems, as well as the required water quality [1]. Therefore, the water supply system must be effectively shielded from various pollutants entering it from the source, including algae, sediments, plankton, debris, as well as juvenile fish [2-5].

For preliminary mechanical water purification from debris, water intake structures are equipped with meshes (flat or rotating), as well as porous cartridges [6]. In water intake wells, mesh or porous filters are installed in sandy aquifers to collect water from underground sources [7]. To retain algae and plankton in water treatment plants, drum meshes and microfilters are used [8], as well as porous tubular structures [9].

Rapid filters are essential in the technological systems of water treatment plants that provide domestic and drinking water supply to towns. Their operation significantly influences water quality, useful capacity, and the technical-economic value of the water treatment plant [10].

The filter operates as follows: during filtration, raw water moves from top to bottom, passing through the filter medium, being collected by the drainage-distribution system, and then directed to further facilities.

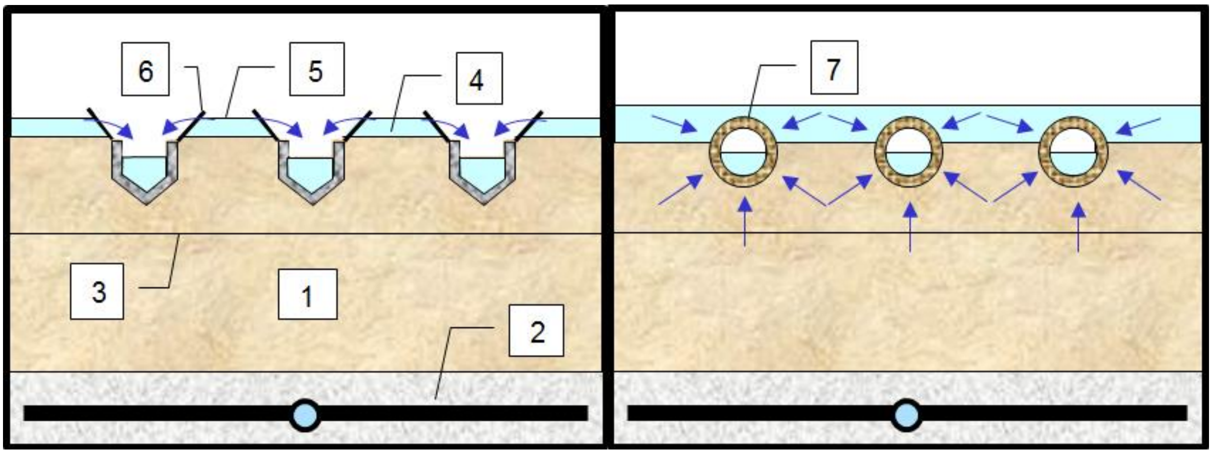
During backwashing, water flows in the reverse direction from bottom to top, is distributed evenly over the filter area by the filter's drainage system, passes through the filter medium, and is discharged outside the filter using wash water collection systems. It should be noted that the filter medium is weighed during backwashing, and smaller particles get in the upper part, often leading to their entrainment. According to the operation data of rapid filters, load loss can reach 10-15% annually; it has to be systematically replenished, thus increasing operating expenses and, consequently, the water cost.

In this regard, one of the main structural elements of rapid filters, which determine their regular technological operation and economic indicators, is the backwash water discharge devices [11], which are subject to the following requirements:

- ✓ Uniform collection of backwash water from the filter area.
- ✓ Sufficient mechanical strength.
- ✓ Prevention of load entrainment.
- ✓ Absence of progressive clogging with suspension and loading.
- ✓ Reliability and durability.
- ✓ Cost-effectiveness.

Porous and mesh devices have been found to have wide applications in the operational practice of rapid water purification filters.

Let us consider designs for draining wash water from rapid filters with horizontal gutters, the edges of which are equipped with inclined meshes and a system of porous pipes (Fig. 1).



a) b)

Fig. 1. Diagram of wash water drainage structures:
a – horizontal gutters with inclined meshes; b – porous pipes:
1 – filter media; 2 – drainage; 3 – loading level during filtering; 4 – level of suspended load during washing; 5 – water level during backwashing; 6 – mesh; 7 – porous pipe

Porous polymer concrete can be used as the material for manufacturing porous pipes. It is composed of gravel or crushed stone and epoxy resin of the "ED – 16" or "ED – 20" brand with a polyethylene polyamine hardener, approved by sanitary authorities for use in domestic and drinking water supply systems. This material has high strength characteristics, increased chemical resistance to aggressive water treated with reagents, and prevents biofouling during extended periods of operation. As can be seen from Fig. 1, when washing the filter, meshes and porous pipes are partially immersed in a layer of suspended loading, and therefore they should not allow particles of the filter material to slip through and prevent them from being carried away outside the filter.

To achieve this, the mesh cell sizes should be selected 0.1 mm smaller than the minimum diameter of the filter media grains, which in domestic drinking water supply systems typically measure 0.5 mm and are commonly encountered in water purification practices. Therefore, the mesh cell size should be approximately 0.4 mm.

The particle size of the filler of porous polymer concrete, which is located in the suspended layer of media (to ensure its non-collapsibility), is determined based on the size of the particles of the filter media according to the corresponding ratio derived in the study [12]. $D'_{av}/d_{min} = 5 – 7.5$. D'_{av} is an average diameter of porous polymer concrete filler. d_{min} is the minimum diameter of the filter media.

In order to achieve the task, the thickness of the porous polymer concrete layer can be chosen in the range of 25–30 mm. Therefore, for media with a minimum particle size of 0.5 mm, the average diameter of the porous polymer concrete filler will be 2.5 – 3.5 mm, corresponding to an average pore diameter of 0.7–1.3 mm, although it may be slightly larger. This assumption is based on the fact that the direction and cross-section of the pore channels vary chaotically throughout the thickness of the porous polymer concrete. It prevents the penetration of media particles into the porous layer. This is one of the main advantages of porous materials compared to the use of mashes, where the openings must be smaller than the size of the retained particles.

The above confirms that the choice is relevant of structures and comparison of their hydraulic characteristics during operation are relevant.

Goals and Objectives. This research aims to compare the dynamics of clogging between porous concrete and mesh, ensuring the non-collapsibility of particles with a size of 0.5 mm used in filtration structures.

Materials and Methods of Research. The studies were conducted on a laboratory setup consisting of a pipe with a diameter of 50 mm and a height of 300 mm (Fig. 2). The setup was filled with quartz sand with a particle size of 0.5–1.6 mm, and a drainage disk made of porous polymer concrete was placed at the bottom. The lateral surface of the setup was equipped with an inspection window with glass to observe the media level.

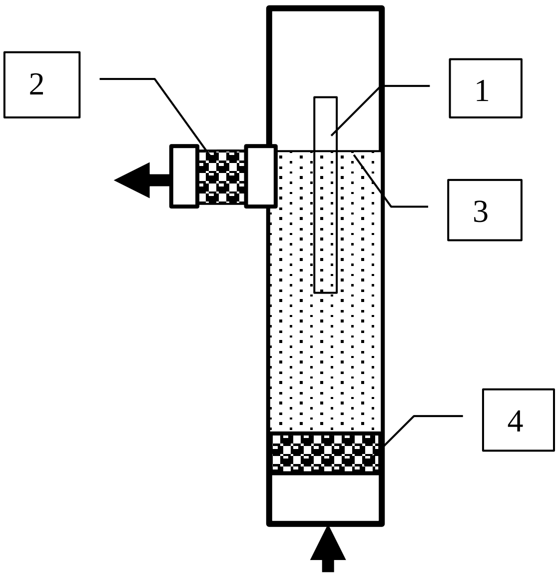


Fig. 2. Scheme of the laboratory setup:
1 – inspection window; 2 – test sample;
3 – level of suspended media; 4 – drainage

Water was supplied from bottom to top at an intensity of 15 l/(s·m^2). During this process, the media was suspended, and the test sample was fully immersed in the suspended layer.

Water drainage was carried out through the samples onto a fine sieve to control the amount of sand passing through them. The test samples were fabricated in a metallic frame with a diameter of 40 mm and a length of 50 mm, in two variants. In the first variant, they were filled with porous polymer concrete with filler sizes ranging from 2.5 to 10 mm and a thickness of 25 mm. In the second variant, they were equipped with a metal mesh with cell sizes of 0.45 mm and a wire thickness of 0.16 mm. The water filtration speed through the samples was 2.7-3.0 cm/s, which corresponded to the data from the tests.

The experiments were conducted in two stages. In the first stage, the initial hydraulic characteristics of the samples made of porous polymer concrete and mesh were studied. In the second stage, their clogging by suspended media particles was investigated. As shown in [13, 14], the coefficient of hydraulic resistance of porous polymer concrete can be determined from a single-term power formula:

$$\Delta h = C\delta_n \nu^{2-n} V_f^{\ n}, \qquad (1)$$

Δh – pressure loss in a porous sample, cm;

δ_n – sample thickness, cm;

υ – kinematic viscosity of water, cm^2/s;

V_f – filtration speed, cm/s;

C – the coefficient, which depends on the granulometric composition of the filler of polymer concrete and the degree of density of its packing (the coefficient *C* also takes into account the clogging of pores by sand particles);

n – exponent, which can be taken equal to 1.67 (at Reynolds numbers $Re = V_f d / \upsilon$ =15-200).

The following formula [15] was used to determine the coefficient of hydraulic resistance of the mesh ξ_c:

$$\xi_c = k_{Re}\xi_{pr}. \quad (2)$$

This formula is valid under the condition $50 < Re < 10^3$, where k_{Re} is the coefficient determined from the graph [14] depending on the Reynolds number.

ξ_{pr} is the coefficient determined by the formula:

$$\xi_{pr} = 1.3(1 - \overline{f}\,) + (1/\overline{f} - 1)^2\,, \quad (3)$$

$\overline{f}$ is the ratio of the total area of all openings in the mesh to the cross-sectional area of the test sample. $\Sigma f_{op}/f_{semp} = 0.4$. Then $\xi_{pr} = 3.03$.

When Re < 50, the coefficient ξ_C can be obtained using the formula [14]:

$$\xi_c = 22/Re + \xi_{pr}. \quad (4)$$

The Reynolds number is determined by the formula:

$$Re = w_{op}\delta_w/\nu\,, \quad (5)$$

w_{op} is the velocity in the openings of the mesh, in cm/s, which is determined by the formula:

$$Re = \frac{V_{semp} \cdot f_{semp}}{\Sigma f_{op}}\,, \quad (6)$$

V_{semp} is the water filtration rate through the sample (2.7–3.0), in cm/s; δw the wire thickness (0.016 cm); υ the coefficient of kinematic viscosity of water in cm2/s, assumed depending on the water temperature (when $t_w = 10^oC$, $\upsilon = 0.0131$).

Thus, the Re number will be 8.2 – 9.2, therefore, to determine the initial resistance coefficient of the grid ξo, one should use the expression (4):

$$\xi_o = 22/8.2 + 3.03 = 5.72.$$

Results of the Research. Initially, the hydraulic characteristics of samples made of porous polymer concrete and mesh were studied to obtain initial coefficients of hydraulic resistance. The experiments were conducted in a laboratory setup (Fig. 2). The results of the experiments are presented in the graphs (Fig. 3 and Fig. 4).

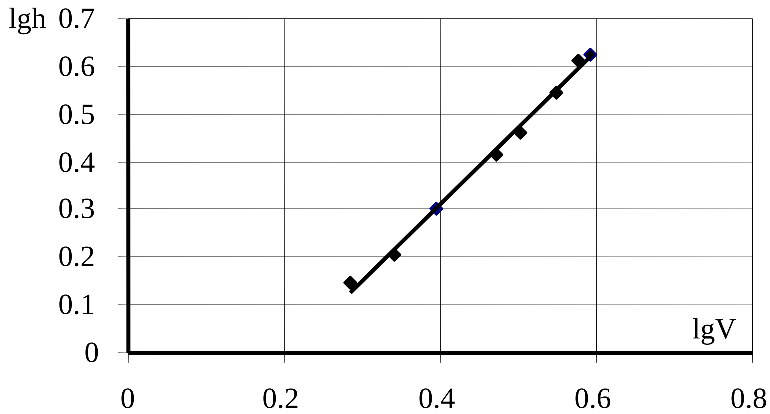


Fig. 3. Dependence of pressure loss on filtration rate in polymer concrete

It should be noted that the experimental study of the hydraulic characteristics of the mesh was carried out in the range of filtration speeds of 7 – 32 cm/s (Fig. 4), which is significantly greater than in the range under study. This was due to the fact that in a given speed range of 2.7 – 3.0 cm/s, the pressure loss in the grid did not exceed 1 mm, which created a significant measurement error.

The next stage of experimental research involved comparing the clogging dynamics with sand between porous polymer concrete and the mesh. For this purpose, the laboratory setup was loaded with quartz sand ranging in size from 0.5 to 1.6 mm. The tests were conducted sequentially, first with the mesh sample and then with the polymer concrete sample. When water was supplied from bottom to top, the loading was approximately 40% weighed down.

A necessary condition for the experiment was the positioning of the samples within the layer of suspended load and maintaining the specified filtration velocity. Simultaneously, control over the sediment transport was carried out.

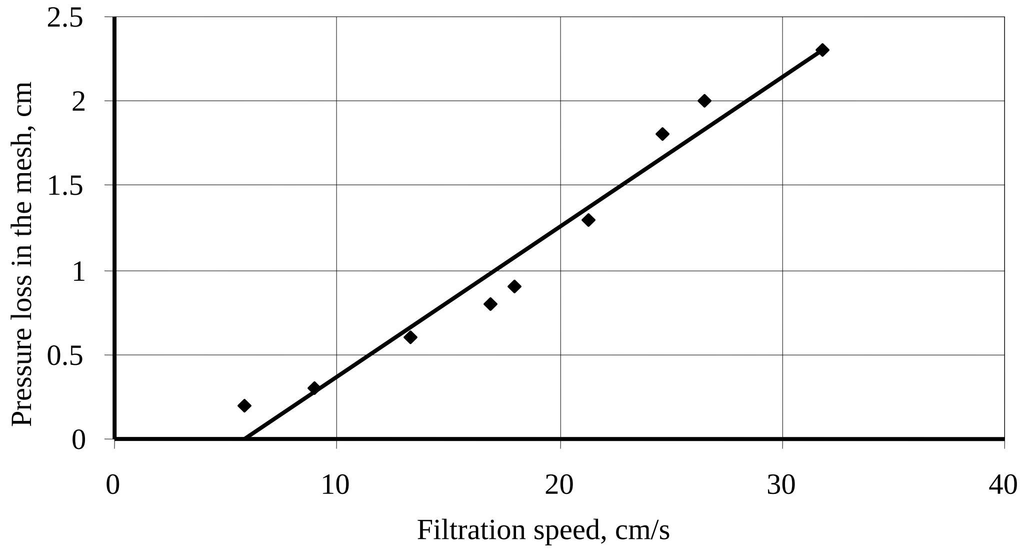


Fig. 4. Dependence of pressure loss on filtration speed in the mesh

The dynamics of changes in the coefficient of hydraulic resistance of porous polymer concrete, denoted as C, over time were analyzed by the dependence $\overline{C} = C/C_0 = f(t)$. C_0 is the initial coefficient of hydraulic resistance. The variation of the mesh resistance coefficient (denoted as $\overline{\xi_c}$) over time was tracked by the dependence $\overline{\xi_c} = \xi_c/\xi_0 = f(t)$. The results of the experiments are presented in graphs (Fig. 5 and Fig. 6).

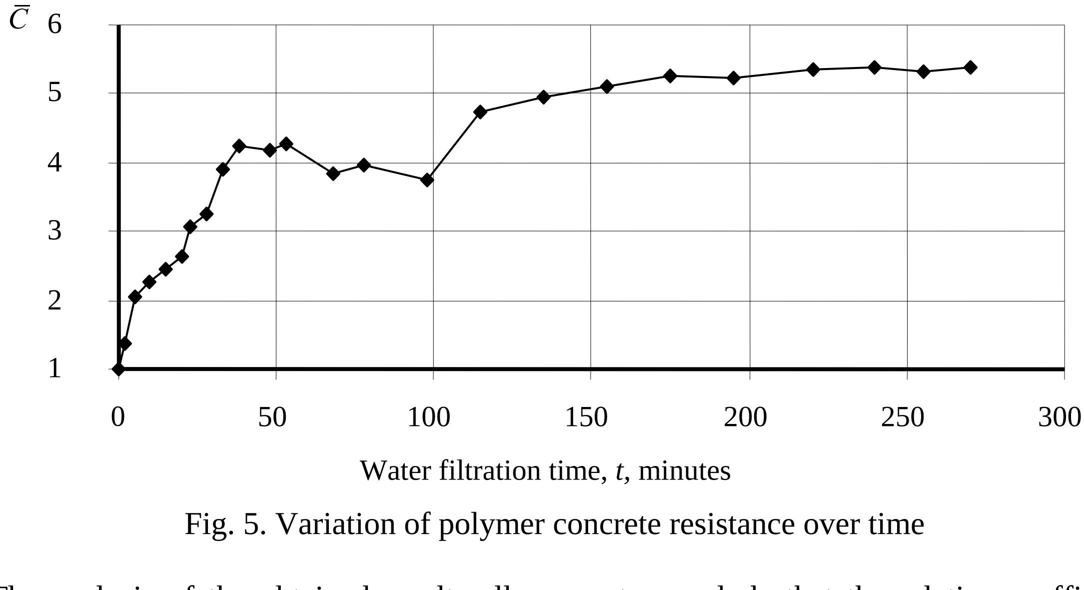


Fig. 5. Variation of polymer concrete resistance over time

The analysis of the obtained results allows us to conclude that the relative coefficients of hydraulic resistance of porous polymer concrete and the mesh initially increase, followed by stabilization, and further growth is not observed: in the first case, after 150 minutes of filtration, and in the second case, after 200 minutes of filtration. There was no loss of filter media in both cases.

At the moment of stabilization, the values of the resistance coefficients significantly differ from each other and are as follows:

– For polymer concrete: $\overline{C}$ = 5.4.
– For the mesh: $\overline{\xi_c}$ = 2110.

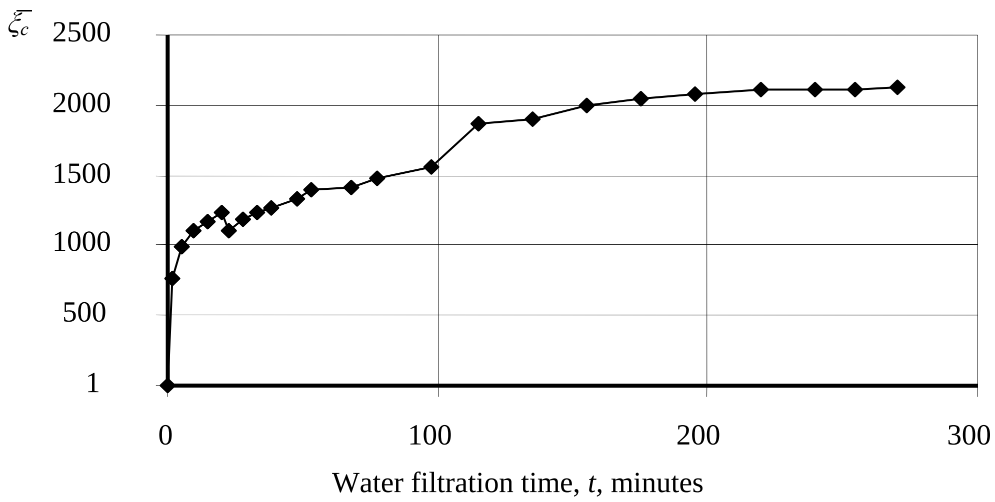


Fig. 6. Variation of the mesh resistance coefficient over time

It should be noted that the growth of coefficients $\overline{C}$ and $\overline{\xi_c}$ at the initial moment of time occurs unevenly: the coefficient $\overline{\xi_c}$ reaches significant values already in the first minutes of filtration. This is due to the fact that the suspended load is pressed against the mesh by the water flow, sharply increasing its resistance ($\overline{\xi_c}$ = 1100). In the subsequent stages, there is a relatively smooth increase in the coefficient $\overline{\xi_c}$, which is associated with the fact that the finest sand particles get lodged in the mesh cells. This fact was visually confirmed at the end of the experiment. It was observed that some sand remained trapped in the mesh cells. The increase in the resistance coefficient of porous polymer concrete is attributed to some penetration of load particles into the pores of the filler; however, this increase is substantially lower than that observed in the mesh.

On the graph (Fig. 7), the change in head losses in porous polymer concrete and the mesh is shown depending on the volume of filtered water at a filtration rate of 2.7 cm/s.

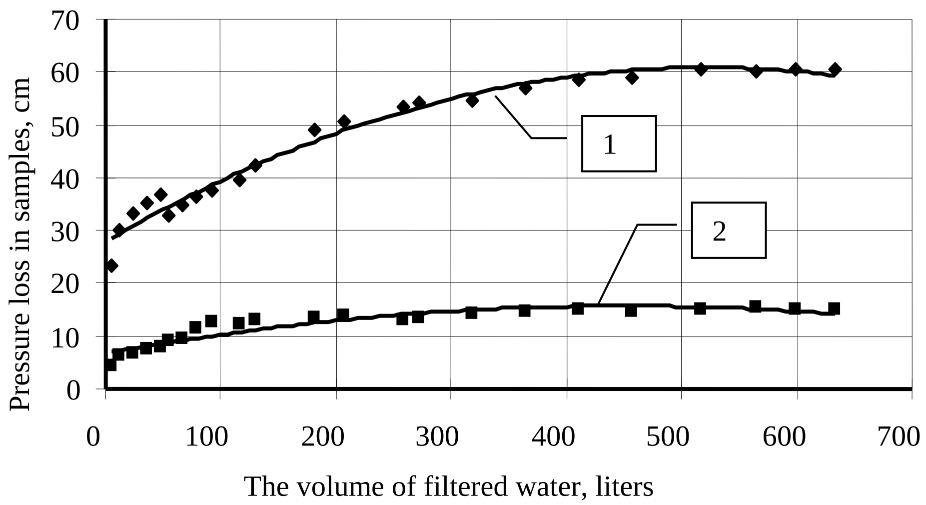


Fig. 7. Relationship between pressure losses and water volume:
1 – in the mesh; 2 – in the polymer concrete

As can be seen from the graph, the pressure loss in the mesh exceeds the pressure loss in polymer concrete by approximately 4 times.

Conclusions:

The hydraulic resistance of samples made of porous polymer concrete was studied for filler sizes ranging from 2.5 to 10 mm. It was established that the relationship between pressure losses in the samples and velocity can be described by a single-term power formula, which was used to develop engineering calculation methods.

The dynamics and extent of clogging of porous polymer concrete and the mesh with sand have been studied. It was found that the hydraulic resistance coefficients of polymer concrete and the mesh initially increase, followed by stabilization. However, their maximum relative values significantly differ from each other:

– For polymer concrete: $\overline{C}$ = 5.4.

– For the mesh: $\overline{\xi_c}$ = 2110.

As a result of the conducted experiments, it was found that the pressure losses in polymer concrete during filtration under suspended load conditions are approximately four times lower than those in the mesh. Visual observation confirmed that the mesh cells become clogged with sand particles. This confirms the advantages of porous polymer concrete.

The task of further research is to develop an engineering methodology for calculating advanced porous structures of filtration facilities and their industrial testing.

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ОБГРУНТУВАННЯ ВИБОРУ ПОРИСТИХ КОНСТРУКЦІЙ ФІЛЬТРОВАЛЬНИХ СПОРУД

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Анотація. Швидкі фільтри є важливим елементом у технологічних схемах очищення природних вод. Вони забезпечують необхідну якість води, корисну продуктивність водоочисних споруд та техніко-економічні показники. Одним із основних конструктивних елементів фільтрів є системи відведення промивної води.

Авторами сформульовані основні вимоги до відвідних пристроїв, а саме – рівномірний збір промивної води з площі фільтра та запобігання винесення фільтруючого завантаження при промиванні. У статті розглянуті два варіанти конструкцій, які цілком відповідають цим вимогам: горизонтальні жолоби, на верхніх кромках яких встановлені похилі сітки або пористі полімербетонні труби.

Зазначається, що сітки та труби при промиванні частково занурені в шар зваженого завантаження і стикаються з найбільш дрібними частинками, що підвищує ймовірність їх винесення. Наводяться дані, що забезпечують запобігання проникненню зерен фільтруючого завантаження крупністю 0,5 мм, яка найчастіше зустрічається у фільтрувальних спорудах систем господарсько-питного водопостачання через похилі сітки та пористий полімербетон.

Виконано експериментальне зіставлення пористих та сітчастих пристроїв у системах відведення промивної води з швидких фільтрів шляхом порівняння їх відносних коефіцієнтів гідравлічного опору. Встановлено, що коефіцієнти гідравлічного опору полімербетону та сітки спочатку зростають, а потім настає стабілізація. При цьому їх максимальні відносні значення суттєво відрізняються один від одного: для полімербетона – 5,4; для сітки – 2110.

В результаті проведених дослідів встановлено, що втрати напору в полімербетоні при фільтруванні в умовах зваженого шару приблизно в чотири рази менше, ніж у сітці через заклинювання сіток частинками піску, що підтверджує переваги пористого полімербетону.

Ключові слова: пористі конструкції, сітчасті пристрої, швидкий фільтр, коефіцієнт гідравлічного опору, пісок.

Стаття надійшла до редакції 08.01.2025