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POROUS DRAINAGES FOR CONTACT CLARIFIERS

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Abstract. Filtering facilities are essential for the technological schemes for natural water treatment. They provide the required water quality as well as the valuable capacity of water treatment facilities. Contact clarifiers are widely used to purify water with low turbidity and high color values. Single-stage filtration based on the principle of contact coagulation uses it. Possible complications in the operation of contact clarifiers are usually related to running the drainage distribution system.

The authors formulated several basic drainage requirements, particularly the uniform distribution of wash water over a space and the absence of filter load removal.

The article analyzes the existing drainage structures (drainage with supporting layers of gravel and a gravelless pipe distribution system), which shows that they do not meet the requirements. They lead to irregular washing of the filter load, a decrease in its dirt capacity, an increase in residual contaminants, a reduction in the filter cycle, and an increase in the maintenance cost.

To improve reliability and durability, a drainage design is proposed that consists of perforated reinforced concrete slabs, with porous polymer concrete in their holes, made of crushed granite or gravel and a polymer binder, i.e., epoxy resin. This construction will ensure a uniform velocity field during washing and filtering, reduce water consumption for its own needs, increase the filter cycle, and prevent possible removal of the filter load.

It is found that the colmatation of the pore space with a suspended matter is one of the main issues when considering the porous drainage in the structure of contact clarifiers.

The article presents experimental studies of the dynamics and degree of the colmatation in porous polymer concrete with polluted water. They showed that no irreversible colmatation happens, and the data obtained will allow us to use them during the hydraulic calculations.

The task of further research is to conduct full-scale tests on existing facilities.

Keywords: contact clarifier, colmatation, drainage, contact coagulation, coefficient of hydraulic resistance.

Introduction. One of the water supply problems in Ukraine and abroad is the purification of highly colored low-turbidity waters, which is typical for a particular category of rivers and reservoirs [1]. Many facilities use modern coagulants and flocculants instead of traditional ones to increase the efficiency of removing natural organic substances. However, this does not always lead to a tangible impact due to insufficient knowledge of the following: the reagent treatment process, depending on the nature of organic contaminants (which cause the color of water), the existing technological and design flaws (which are inherent in the very beginning of the purification process, when introducing reagents and mixing with the flow of the treated water) as well as – the organization of the process of flocculation.

Contact clarifiers (CC) are a more complete solution to the problem of purification of high-color low-turbidity waters. They are structures for clarification and decolorization of water, combining the functions of a flocculation chamber, a sump, and a quick filter. The action of CC is based on the principle of contact coagulation, which lies in the fact that when water moves through a layer of granular loading, colloidal and suspended aggregately unstable parts are adsorbed on the surface of the grains of the filter material. It provides, just as in contact filtration, more complete coagulation, the possibility of reducing the doses of reagents, and the independence of the required amounts from the temperature and alkalinity of the water [2]. In this regard, improving the CC's design parameters is relevant to ensure their regular operation.

Analysis of recent research and publications. There are several types of contact clarifiers CC-1, CC-2, and CC-3. Structurally, CC-1 does not differ from a conventional fast filter. It is a reinforced concrete rectangular tank (Fig. 1) with a load of granular layers constantly decreasing from the bottom up. So the central part of the contaminants is retained in the lower coarse-grained layers. In this design, the filtrate is being removed from the overload water layer. At the same time, the filtration rate (with an average sand grain size of 0.8 mm) should not exceed 5-5.5 m/h to avoid sand weighing. In CC-2 clarifiers, the filtrate is being removed from the upper part of the filter layer. It allows to increase the calculated filtration rate (up to 10 m/h) but raises the cost of the drainage system. The CC-3 clarifiers use water-air washing of the filter loading. CC-3 has a "low horizontal outlet" for the wash water. Moreover, CC-3 clarifiers can have two drainage systems for air and water.

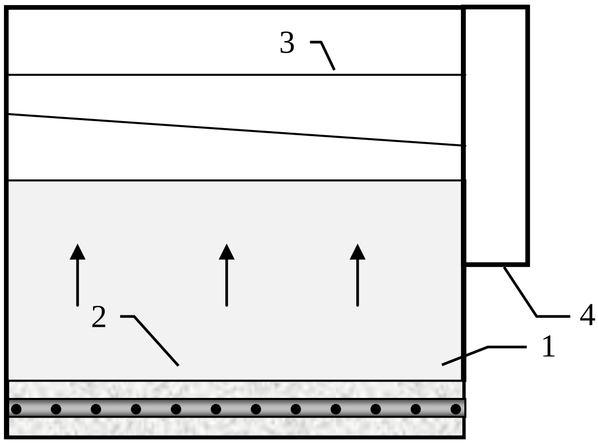

Fig. 1. contact clarifier CC-1: 1 – filter loading; 2 – drainage; 3 – gutter; 4 – collecting channel

The efficiency of water purification at CC is determined mainly by the operation of the drainage distribution system. And the operational experience shows it is the most often tricky part [3, 4]. There are several requirements for CC drainages, particularly the uniform distribution of wash water over a space and the absence of filter load removal. However, existing drainage designs do not always meet these requirements. It leads to irregular washing of the filter load, a decrease in its dirt capacity, an increase in residual contaminants, a reduction in the filter cycle, an increase in the maintenance cost, and reducing the overall reliability of the CC [5, 6].

For a long time, CC drain designs have used a high-resistance tubular distribution system with supporting gravel levels similar to fast filter drains. A significant disadvantage of such drainages is the possibility that gravel layers will shift during flushing, leading to a complete shutdown of the CC and the need for overhaul [7].

Later, a gravelless tubular distribution system (GTDS) was developed, a method of distribution pipes with 10–12 mm holes in diameter, staggered and directed downward at an angle of 30° to the vertical axis of the pipe [8].

Vertical metal curtains are welded to the pipes on their sides without reaching the bottom of the CC. Between the shutters, transverse partitions are welded, reaching the bottom and dividing the underripe space into cells (Fig. 2).

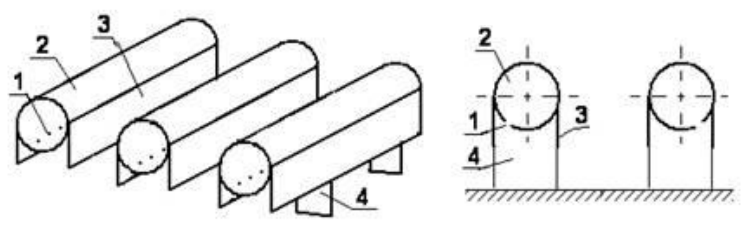

Fig. 2. Gravelless tubular distribution system (GTDS) for a CC:
a – appearance; b – transect; 1 – holes in pipes; 2 – water distribution pipes; 3 – side curtains; 4 – transverse partitions

The advantage of GTDS is the absence of supporting layers; the disadvantage is the need for drainage from steel pipes, their possible corrosion, and the complexity of welding and installation. When flushing water is supplied by pumps (without a tower), there is a risk of sand entering the drainage pipes during an emergency power outage.

Therefore, using porous materials in drainage devices will significantly improve their performance and ensure the fulfillment of their requirements.

Odesa State Academy of Civil Engineering and Architecture (OSACEA) has developed several design options for the drainage of rapid water treatment filters based on porous polymer concrete. The most common of them are tray and perforated [9].

The first one consists of polymer concrete slabs mounted on supporting concrete walls (Fig. 3). Branch pipes are installed at the inlet to each tray. The resistance of branch pipes ensures the required uniform distribution of water flow rates between the channels.

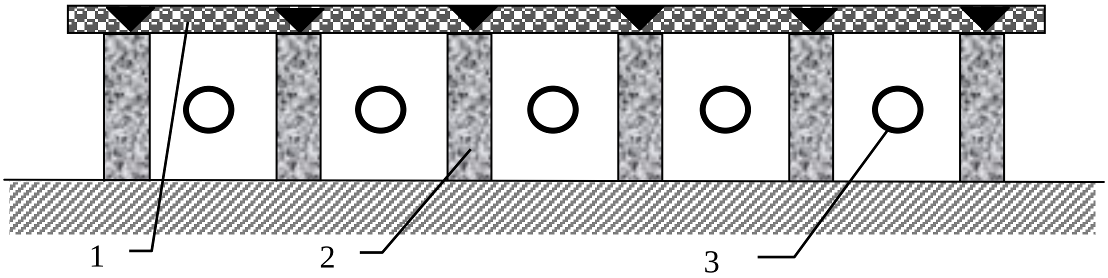

Fig. 3. Tray design of polymer concrete drainage:
1 – porous slab; 2 – supporting concrete walls; 3 – branch pipes of high resistance

In cases of increased requirements for water quality (for example, in terms of silicon content), there are structures that consist only of plastics, the base of the drainage is a vinyl plastic sheet, and the porous layer is made of polystyrene. There is a modification designed not only for water but also for water-air and alternating flushes.

The second structure consists of a reinforced concrete slab (Fig. 4), the holes filled with porous polymer concrete with a size of 7-10 mm. From above, it is also covered with a layer of porous polymer concrete with a size of 3-5 mm and a thickness of 20 mm to prevent the formation of "dead" zones between the holes.

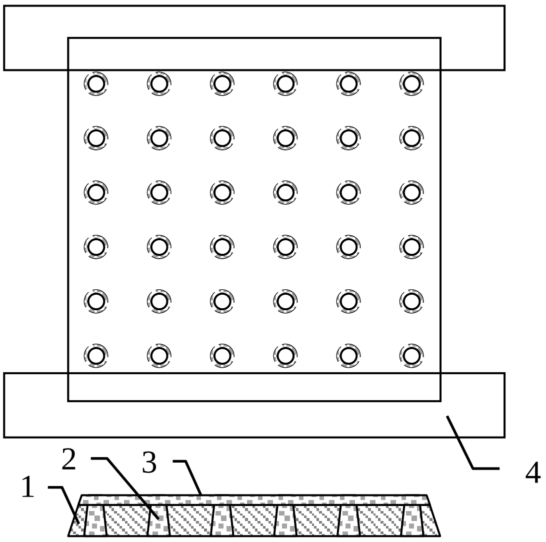

Fig. 4. Drainage slab:
1 – reinforced concrete slab; 2 – holes filled with polymer concrete; 3 – a layer of polymer concrete; 4 – supporting elements

Plates are mounted on supporting elements. Holes in the slabs are tapered upwards to prevent the separation of polymer concrete from reinforced concrete. The side ends of the plates are beveled to simplify the sealing of joints after the installation of the plates.

In this design, in comparison with the tray, due to the reinforced concrete frame, the drainage has a greater bearing capacity, and simultaneously, the consumption of expensive polymer concrete is reduced.

Both designs have been successfully implemented on fast filters of many water pipelines in Ukraine and other countries. They have shown reliable operation over a long service life.

Porous structures are made of porous polymer concrete made of gravel or crushed stone and epoxy resin grade ED–16 or ED–20 with a polyethylene polyamine hardener permitted by the Ministry of Health of Ukraine for drinking water supply systems. This material has high strength, increased chemical resistance to the aggressive effects of water treated with reagents, and the absence of biofouling during long-term operation [10].

Goals and tasks. The colmatation of the pore space with a suspended matter is one of the main issues when considering the porous drainage in the structure of contact clarifiers. In this regard, the present research aims to study the dynamics and degree of the colmatation in porous polymer concrete with polluted water.

Materials and research methods. The Department of Water Supply of OSACEA has already done studies of this kind. However, they related to the designs of drainages and systems for removing wash water from fast filters [11]. In this case, the movement of water was carried out with flow reversal during washing and filtering, which reduced the overall degree of polymer concrete colmatation.

A feature of CC is that the movement of water in the process of filtering and washing goes in the same direction. In addition, unlike fast filters, it is not the filtrate that enters the drainage but raw water with the coagulant introduced into it. Therefore, there is a possibility of irreversible colmatation of the pore space of the polymer concrete with a suspension and flakes of the coagulant. In other words, contact coagulation may start not in the filter loading but in the porous drainage, which will complicate the further work of the CC.

Given the above, CC drainage can be a structure consisting of perforated reinforced concrete slabs with porous polymer concrete filled in their holes. This construction will ensure a uniform velocity field during washing and filtering, increase reliability and durability and prevent possible removal of the filter load. Compared to the tray design, the speed of water movement in the holes, especially during flushing, will be several times higher, which should help restore its capacity.

To test the assumptions, experimental studies were carried out to check the dynamics of colmatation of porous polymer concrete on a laboratory installation, which consists of two tanks located one above the other with a capacity of 150 liters each. The tanks are connected by a vertical pipe 40 mm in diameter with flanges in the middle, and a test sample made of porous polymer concrete was placed between them. The water became polluted in the upper tank to a concentration of 50-60 mg/l; the coagulant aluminum sulphate was included with a dose of 20 mg/l [8].

The test sample was made in a metal case 40 mm in diameter with two-layer porous polymer concrete: the first layer was 7–10 mm in size and 70 mm thick; the second layer was 3–5 mm and 20 mm thick. The pressure loss in a porous layer is generally described by a two-term additive dependence [12]:

$$h_c = \mathrm{H} - \mathrm{h} = a_2 V_f + b_2 V_f^2 , \tag{1}$$

where H is the piezometer above the sample; h is the piezometer under the sample; V_f is the rate of filtration through a porous sample; a_2 and b_2 are coefficients that depend on the characteristics of the porous sample wall (thickness, grain diameter, porosity), water viscosity and are usually determined experimentally.

The main advantage of this formula is that it can be used over a wide range of Reynolds numbers. At low filtration rates (and low *Re*), the second term becomes negligible, and formula (1) corresponds to the Darcy formula. Only the second term of the formula works at high speeds, and the dependence of pressure loss on speed is quadratic. However, as the analysis showed, fluid movement through the porous walls of the drains occurs in a transient mode, so both terms of the formula must be used here. And this requires the determination of two empirical coefficients – a_2 and b_2, which creates difficulties in engineering calculations.

However, the two-term formula (1) can be replaced by a one-term power formula that is more convenient for calculations [13]:

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

where Δh is the pressure loss in a porous sample, cm; δp – sample thickness, cm; υ is the kinematic viscosity of water, cm^2/s; V_f is the filtration rate, cm/s; C is a coefficient depending on the granulometric composition of the polymer concrete filler and the degree of density of its laying (in the case of filtering contaminated water, the coefficient C also takes into account the colmatation of pores by suspended particles); n is the exponent, which can be taken equal to 1.67 (determined empirically).

With a constant exponent n, to use formula (2), it is enough to know only one value – the coefficient C.

The studies were carried out in two stages: at the first stage, the hydraulic characteristics of the sample were studied, and at the second stage, the degree of its colmatation with a suspension.

The purpose of the first stage of research was to obtain the initial coefficient of hydraulic resistance *C* on pure water.

Raw water with a turbidity of 50 mg/l and treated with aluminum sulfate coagulant was filtered through the sample at the second stage of the experiment. The sample was washed with clean water for 6 minutes after 8 hours. Thus, the operation of CC during filtration and washing was simulated. The speed during filtration was 2-2.2 cm/s, while during the washing it was 24 cm/s. This would correspond to production data.

Research results. The dynamics of changes in the coefficient of hydraulic resistance of porous polymer concrete C in time were carried out by plotting the dependence $\bar{C} = C/C_o = f(t)$, where C_o is the initial coefficient of hydraulic resistance. The results of the experiments are presented in the graph (Fig. 5).

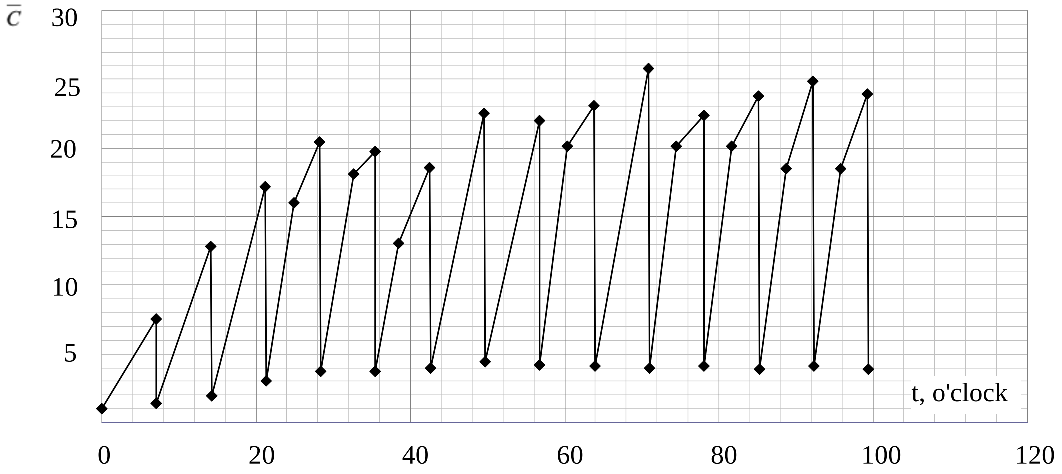

Fig. 5. Change in hydraulic resistance coefficient $\bar{C}$ over time

The upper points correspond to the change in the coefficient $\bar{C}$ during filtration; the lower points equal the change in the coefficient during washing.

It can be seen from the graph that the coefficient initially grows, and then, starting from 50 hours of operation (approximately six filter cycles), it stabilizes and subsequently remains practically unchanged. In this case, the maximum values of $\bar{C}$ are about 24 during filtration and 4, respectively, during washing, which indicates a partial recovery of the throughput of the sample. The nature of the obtained curve corresponds to the results of previous work on the study of polymer concrete colmatation at the Department of Water Supply.

Therefore, experimental studies' data can be considered in the engineering method of hydraulic calculation of perforated polymer concrete drainage of CC.

However, it should be noted that the conclusion on the possibility of using porous drainage in CC structures can only be made after conducting field studies on existing systems.

Conclusions:

1. Using porous drains in CC designs will improve the uniformity of distribution of wash water over the area, reduce water losses for own needs, increase the filter cycle, and increase the reliability of CC operation. At the same time, the irreversible colmatation of porous polymer concrete does not occur, as confirmed by laboratory studies.
2. The task of further research is to conduct full-scale tests on existing structures.

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ПОРИСТІ ДРЕНАЖІ КОНТАКТНИХ ОСВІТЛЮВАЧІВ

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Анотація. Фільтрувальні споруди є важливим елементом у технологічних схемах очистки природних вод. Вони забезпечують необхідну якість води та корисну продуктивність водоочисних споруд. Для очищення малокаламутних вод з високими показниками кольоровості широке застосування знайшли контактні освітлювачі, які використовуються при одноступінчастому фільтруванні, заснованому на принципі контактної коагуляції. Можливі ускладнення у роботі контактних освітлювачів нерідко пов'язані з функціонуванням дренажно-розподільчої системи.

Авторами сформульовано ряд основних вимог, які пред'являються до дренажів цих споруд, а саме – забезпечення рівномірного розподілу промивної води по їх площі та недопущення винесення фільтруючої загрузки.

У статті наведено аналіз роботи існуючих конструкцій дренажів (трубчастий дренаж з підтримуючими шарами гравію і безгравійна трубчаста розподільна система), який показав, що ці конструкції не забезпечують виконання вимог, які пред'являються до них. Це призводить до нерівномірного промивання фільтруючого завантаження, зниження її брудоємності, зростання залишкових забруднень, скорочення фільтроциклу, збільшення витрат на власні потреби.

Для підвищення надійності та довговічності запропоновано конструкцію дренажу, яка складається з дірчастих залізобетонних плит, отвори яких заповнені пористим полімербетоном, виробленим на основі гранітного щебеню або гравію та полімерного зв’язуючого – епоксидної смоли. Ця конструкція дозволить забезпечити рівномірне поле швидкостей при промиванні та фільтруванні, скоротити втрати води на власні потреби, збільшити фільтроцикл, запобігти можливому винесенню фільтруючого завантаження.

Встановлено, що одним із головних питань, що виникають при розгляді можливості застосування пористих дренажів у конструкціях контактних освітлювачів, є кольматація їх порового простору завісю.

У статті наводяться результати експериментальних досліджень динаміки та ступеня кольматації пористого полімербетону забрудненою водою, які показали, що незворотної кольматації не відбувається, а отримані дані дозволять використовувати їх при виконанні гідравлічних розрахунків.

Завданням подальших досліджень є проведення натурних випробувань на діючих спорудах.

Ключові слова: контактний освітлювач, кольматація, дренаж, контактна коагуляція, коефіцієнт гідравлічного опору.

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