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Maximum permissible technological parameters of frame-filling filters

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Abstract

Relevance. Wastewater of knitting industry contains various types of dyes, synthetic surfactants, mineral salts and suspended solids in values requiring deep cleaning. It is advisable to carry out deep cleaning of these drains on non-pressure filters, which do not require large expenses and are easy to operate. We gave preference to frame-filling filters. First of all, it allows significant increase in filtration rate, and its two layers with different fractions of filter materials significantly contributes to differentiated purification of wastewater from suspended solids of various sizes. **Aim.** To determine the maximum permissible values of technological parameters of the frame-filling filters operation (filtration rate and duration of the filter cycle) at which high filtration effect is provided through a highly porous material-crushed expanded clay. **Objects.** Wastewaters of the knitting industry and the effluents of the cotton and textile industries that are similar in their composition of pollution, as well as the identical effluents of some other branches of light industry. **Methods.** The experimental method was used on a laboratory frame-filling filter installation. The expanded clay used was obtained by the method of swelling low-melting clays and clay rocks during their rapid firing, followed by crushing to the state of sand. In general, the proposed technological methods are justified by those comparative and generalizing methods that can improve frame-filling filter operation. **Results and conclusions.** Based on the results of the conducted research, the following conclusions can be drawn: (1) Pronounced intergranular porosity (on average 1.6 times greater than that of quartz sand) allows expanded clay granules passing through a significant amount of waste water at relatively high filtration speeds (20–22 m/h) and retain up to 70% of suspended solids; (2) The duration of the filter cycle when using crushed expanded clay is at least 1.5 times longer than when using quartz sand; (3) Due to the greater difference in the average coefficients of the shape of the filtering materials, more complete regeneration of filtering properties of crushed expanded clay compared to quartz sand is provided 2–3 minutes earlier, regardless of the initial concentration of suspended substances; (4) The filtering properties of crushed expanded clay during deep wastewater treatment of the knitted production with the main concentrated pollution indicators (color intensity, BOD_{full}, COD and surfactants) practically do not concede the quartz sand properties. Besides, crushed expanded clay is much cheaper than quartz sand; it can be used on an equal footing with quartz sand for deep cleaning of low-turbidity and slightly colored industrial wastewater.

Keywords: frame-filling filter, suspended substances, fine-grained filter material, highly porous crushed expanded clay, filtering rate, optimal parameters.

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Предельно допустимые технологические параметры работы каркасно-засыпных фильтров

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Аннотация

Актуальность. Сточные воды трикотажной промышленности содержат в своем составе разнообразные виды красителей, синтетические поверхностно-активные вещества, минеральные соли и взвешенные вещества в значительных, требующих глубокой очистки. Глубокую очистку этих стоков целесообразно провести на безнапорных фильтрах, которые не требуют больших расходов и легки в эксплуатации. Нами предпочтение было отдано каркасно-засыпным фильтрам, т. к. они позволяют значительно повысить скорость фильтрования, а два их слоя с разными фракциями фильтрующих материалов способствуют дифференцированному очищению сточных вод от взвешенных веществ различной крупности. **Цель:** определение предельно-допустимых значений технологических параметров работы каркасно-засыпного фильтра (скорости фильтрования и продолжительности фильтроцикла), при которых обеспечивается довольно высокий эффект фильтрации через высокопористый материал – дробленый керамзит. **Объекты:** сточные воды трикотажной промышленности и близкие по своему составу загрязненные стоки хлопчатобумажной и текстильной промышленности, а также идентичные стоки некоторых других отраслей легкой промышленности. **Методы:** экспериментальный метод на лабораторной установке каркасно-засыпного фильтра. Использованный керамзит был получен методом вспучивания легкоплавких глин и глинистых пород при быстром их обжиге с последующим дроблением до состояния песка. В целом предлагаемые технологические методы обоснованы теми сравнительными и обобщающими методами, которые могут улучшить работу каркасно-засыпного фильтра. **Результаты и выводы.** Исходя из результатов проведенных исследований, можно сделать следующие выводы: 1. Ярко выраженная межзерновая пористость (в среднем в 1,6 раз больше, чем у кварцевого песка) позволяет гранулам керамзита пропускать через себя значительное количество сточной воды при относительно больших скоростях фильтрования (20–22 м/ч) и задерживать до 70 % взвешенных веществ. 2. Продолжительность фильтроцикла при применении дробленого керамзита как минимум в 1,5 больше, чем при применении кварцевого песка. 3. За счет большей разности средних коэффициентов формы фильтрующих материалов более полноценная регенерация фильтрующих свойств дробленого керамзита по сравнению с кварцевым песком обеспечивается на 2–3 минуты раньше, независимо от рассмотренных исходных концентраций взвешенных веществ. 4. Фильтрующие свойства дробленого керамзита при глубокой очистке сточных вод трикотажного производства с основными концентрированными показателями загрязнений (интенсивность окраски, БПК_п, ХПК и ПАВ) практически не уступают свойствам кварцевого песка, и к тому же дробленый керамзит намного дешевле кварцевого песка, поэтому его наравне с кварцевым песком можно применять при глубокой очистке маломутных и слабоокрашенных производственных сточных вод.

Ключевые слова: каркасно-засыпной фильтр, взвешенные вещества, мелкозернистый фильтрующий материал, высокопористый дробленый керамзит, скорость фильтрования, оптимальные параметры.

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Introduction

When treating industrial wastewater, frame-filling filters (FFF), developed by B.A. Mitin are widely used [1]. FFF are mounted in standard filters or any containers that meet functional requirements [1, 2]. The operation of these (and other granular) filtration facilities is largely determined by filtration properties of a filter material itself and fractional arrangement of loading layers [3–5].

The FFF combination of two fractions of granular material with several dozen times different grain sizes gives the filter layer properties that neither fine-grained nor coarse-grained loads have individually [4–7].

The main advantage of FFF, in comparison with other types of filters, is the principle of filtration in direction of decreasing grain size of the loading. In this case, the wastewater with the highest concentration of impurities passes through the coarse-grained layer first and then enters the layer with fine grains that have already been sufficiently purified [4, 8, 9]. Thanks to this, silting of the fine-pored backfill does not occur, and more uniform distribution of contaminants along

the height of the filter is achieved. At the same time, the rate of increase in pressure loss is significantly reduced.

The FFF has a peculiar principle of loading regeneration, which consists in the fact that during washing, fine-grained backfill is weighed and moved into the pores of the frame, which remains stationary. At the same time, the backfill itself is washed simultaneously and the surface of the frame grains is cleaned.

FFF also refers to fast filters with high dirt capacity. An increase in this parameter and filtration rate is possible with the use of multilayer filters, new filter materials with high adsorption capacity, as well as the use of various reagents that improve the suspension retention.

We can note the specialized non-woven material “Megasorb” as new filter materials with a high adsorption capacity. It was successfully used in non-pressure filters when treating wastewater from car washes and transport enterprises [10], granular polymer and expanded clay loadings, the use of which

significantly intensified oily wastewater purification [11], as well as granular peat, the use of which provided up to 75–98% of stormwater and surface treatment [12, 13].

Structures with immobilized microflora on granular loading into filtration-type structures are becoming widespread [14].

In addition to the development of effective methods for industrial wastewater treatment by sand filtration [15], the regularities of combined (bio-coal-sand [16], nanocellulose, by filtration [17]), hybrid (coagulation-intermittent-sand [18]) filtration are also being studied. In particular, in [19], coal fly ash was used as the main frame material for manufacturing a ceramic foam filter, and the authors of [20] suggest light expanded clay and clay bricks as substrates instead of gravel.

It should be noted that the filtration method has always been considered by us as an intermediate stage in development of a technological scheme for deep wastewater treatment of textile, cotton and knitting industries. In the long term, the generalized results obtained can be compared with similar results of more modern works [21–23].

Among highly porous materials, granular open-cell elastic polyurethane foam (PUF) with porosity of 96–98% [24] and elastic synthetic fiber with porosity of 88–90% [25] can be noted.

However, the listed filter materials do not differ in their cheapness, they are more labor-intensive in operation, and are quite specialized in their application. Therefore, we selected crushed claydite as a highly porous filling, the porosity of which ranges from 53 to 74% [3, 6–8, 24, 26].

Despite these advantages, there are numerous constructive and technological methods to enhance the FFF operation.

Selection of optimal design parameters (fractions of filter grains and thickness of their layers). The FFF was based on the data we obtained before for identical wastewater from the cotton and textile industries [6, 9, 26, 27]. In this part, only some adjustments were made and only the main technological parameters are considered in the work. They are: the issues of determining optimal and maximum permissible filtration rates and duration of the filter cycle when using highly porous backfilling of crushed claydite. The data obtained are compared with the data for quartz sand.

The search for methods for intensifying wastewater treatment by filtration shows that higher results can be achieved with a simultaneous approach to improving both the design parameters of the filter and the technological parameters of filtration. Among the technological parameters, the trends of accelerating filtration and increasing the filter cycle period are particularly supported.

Materials and methods

The proposed technological methods and available constructive proposals are substantiated by those comparative and generalizing methods that, in principle, can improve the FFF performance.

Theoretically, separating impurity particles from wastewater during filtration comprises three stages: transfer of particles from the wastewater stream to the surface of the filter material, their fixation on the surface of the grains and in the cracks between them, and separation of particles with their transition back into the wastewater stream. The phenomena of inertia and diffusion play the main roles in transferring particles. The retention of particles by the surface of the filter material mainly occurs due to particle adhesion because of the action of intermolecular Van Der Waals forces.

Practically, the regularities of impurity particles filtration were studied according to a generally accepted indicator – the release of suspended solids from industrial wastewater.

The experimental filtration plant was assembled in the basic laboratory of the Institute of Water Problems and Hydro-Engineering named after I.V. Yeghiazarov of Yerevan and consisted of a dark gray plastic cylinder with a thickness of 8 mm, an inner diameter of 25 cm, and a total height of 1.8 m (Fig. 1).



Fig. 1. Laboratory installation of a frame-filling filter
Рис. 1. Лабораторная установка каркасно-засыпного фильтра (КЗФ)

The studied model drain was fed from the top of the central part, and the filtrate was discharged through the lower (on the right side of the filter) hose. The upper convex part provided a uniform supply of wastewater across the cross-section during cleaning, and the lower concave part – during washing the laboratory installation. Provided at heights of 0.42, 0.86, and 1.30 m, diverting hoses with clamps (on the right side) allowed taking samples for analysis and monitoring the dynamics of filtration for retention of suspended substances. The flushing water was supplied from below through the fitting provided in the central part and was discharged through the upper (on the left side) hose.

A valve installed on the discharge line by changing the flow rate of wastewater coming from the filter regulated the filtration rate. The filtration rate remained constant during each cycle of the FFF operation and varied only when a new cycle started.

It should be noted that the laboratory installation, the schematic diagram of which is similar to the scheme described in the following studies [6, 26], is assembled with promising capabilities. In particular, with the help of an additional hose provided on the lower left side, it is possible to carry out separate studies on the upstream filtration flow, and the horizontal plane provided above the filter can serve as a stand for the necessary equipment (dispenser, mixer, etc.), when studying the regularities of reagent filtration.

In this laboratory installation of the FFF, all the research was carried out on the retention of suspended substances, the reduction of chemical oxygen demand (COD) and biological oxygen demand (BOD_{full}), surface-active substances, as well as the optimal technological filtration parameters for the selected design parameters of the filter.

Gravel with a fraction size of 40...50 mm was used as a loading (frame), and fine-grained (0.63–1.0 mm) and medium-grained 1.0–1.6 mm quartz sand or

crushed claydite were alternately used as filling (in a mixed layer together with gravel).

In general, quartz sand is quite wear-resistant and, in comparison with other filtering materials, provides optimal dirt capacity. Therefore, it was used as a reference in the work.

The main component of quartz sand is silicon dioxide (quartz), the content of which in the initial mineral is usually not less than 93–95%. Its formula is SiO₂, but its composition may also contain organic impurities, clay, iron oxides and other metals.

Claydite also has sufficient mechanical strength and is resistant to corrosion. But the most important advantages of claydite are its low price, availability, practicality, efficiency of use, and durability.

The chemical composition of crushed claydite includes 95% CaCO₃ and 5% MgCO₃. Since claydite is made of clay and slate, it is one of the most environmentally friendly materials.

Claydite density can be increased by crushing, after which the specific surface area of pore channels also increases and more favorable conditions for filtration are created. When a highly porous backfill is used, the duration of the filter medium protective action increases while the pressure growth rate decreases. Under these conditions, it becomes possible to increase the filtration rate without deterioration of the filtrate quality.

The studied claydite was obtained by the method of swelling low-melting clays and clay rocks during their rapid firing (1050–1350°C). After heat treatment, claydite gravel was crushed to the consistency of sand and sorted into fractions through hummingbird sieves, followed by washing and drying at 105°C. The main physical and mechanical properties of this crushed fine-grained claydite were obtained in the laboratory "Building Materials and Structures" of the National University of Architecture and Construction of Armenia (NUACA), and together with the data on claydite and quartz sand properties obtained by other researchers [3, 7, 8] are presented in Table 1.

Table 1. Basic physical and mechanical properties of the studied filter materials

Таблица 1. Основные физико-механические свойства исследованных фильтрующих материалов

Material Материал	Grain diameter, mm Диаметр зерен, мм	Density, g/cm ³ Плотность, г/см ³	Mechanical strength, % Механическая прочность, %		Porosity, % Пористость, %	Grain shape coefficient Коэффициент формы зерен
			abrability истираемость	grindability измельчаемость		
Quartz sand [3] Кварцевый песок	0.5...3.0	2.4...2.6	0.5	2.7	38...42	1.07...1.17
Quartz sand [7] Кварцевый песок	0.63...0.80	2.02	0.4	0.07	36...45	–
Crushed claydite [8] Керамзит дробле- ный	0.9 1.78	1.7...1.8 1.68	3.31 2.12	0.63 0.12	74 66	– 4.39
Crushed claydite Керамзит дробле- ный	0.8...1.5	1.3...1.6	3.3	0.15	58...64	2.35

In addition to the data given in Table 1, the data of various researchers [6, 8] also confirm that the values of the characteristic physico-chemical components of quartz sand and crushed expanded clay separately fluctuate within significant limits. In particular, the values of the most important component – quartz sand porosity ranges from 36–45%, and crushed expanded clay is usually in the range of 58–74%. This is mainly due to the content of the corresponding raw materials (untreated sand or clay rocks) and the specifics of their processing.

The filter efficiency is determined by the filtration rate, which should be understood as the speed of water vertical movement over the filter layer.

The filtration rate (V) was determined by the ratio

$$V = Q/A, \quad (1)$$

where Q is the amount of water passing through the filter in a unit of time; A is the filter area.

According to expression (1), the filtration rate is directly proportional to the flow rate of water (wastewater) and inversely proportional to the filter surface. But since the surface (cross-section) of the laboratory installation is a constant value, the speed was regulated by the flow rate of the studied wastewater.

The pressure loss per unit thickness of the filter layer (i_0) is determined by the following formula:

$$i_0 = \psi \frac{V}{d_s^2}, \quad (2)$$

and the pressure loss in the clean filter layer (h_0) is determined by the following formula:

$$h_0 = i_0 \cdot L = \psi \frac{VL}{d_s^2}, \quad (3)$$

where ψ is the wastewater viscosity; d is the grain diameter of the filter material; L is the thickness of the filter layer.

It follows from expression (2) that the unit pressure losses in the pure filter layer increase in proportion to the filtration rate and the water viscosity and increase significantly with a decrease in the grain size and porosity of the filter material.

It also follows from expression (3), that the pressure loss in the clean filter layer is in direct proportion to the thickness of the layer.

It should be noted that the height of the mixed layer (gravel + high-silica sand or gravel + crushed expanded clay) was assumed to be 1.05–1.10 m in all series of experiments. The immutability of this indicator made it possible to more accurately assess the ratio of other indicators.

On the basis of the general stock of the knitting factory “TOSP” in Yerevan studied a 5-fold diluted

model runoff with the following indicators: color intensity by dilution – 1:40–1:50, suspended solids – 36–48 mg/l, BOD_{full} – 135–170 mg O_2 /l, COD – 240–260 mg O_2 /l, surface-active substance (SAS_{total}) – 11–23 mg/l.

Since we previously obtained high purification efficiency at the FFF, when using crushed expanded clay and quartz sand to detain suspended solids at their initial concentrations of about 20 mg/l [6, 9, 26, 27], at this stage studies were conducted at higher values of suspended solids in order to investigate the maximum permissible filtration rates and the duration of filter cycles.

The data from the research results based on the total runoff of knitting production are given in Table 2.

Table 2. Purification data of the total runoff of knitted production at the FFF

Таблица 2. Данные очистки общего стока трикотажного производства на КЗФ

Filter materials Фильтрующие материалы	Fineness of grain, mm Крупность зерен, мм	Filtration rate Скорость фильтрования, м/ч	Value of suspended substances, mg/l Значение взвешенных веществ, мг/л		
			in initial drain в исходном стоке	in filtrate в фильтрате	efficiency, % эффективность, %
Gravel+ quartz sand Гравий+ кварцевый песок	0.63...0.8	12	48	14	70.0
	0.8...1.0	14	43	13	69.7
	0.8...1.0	14	38	11	71.1
	0.63...0.8	15	46	14	69.5
	0.8...1.0	16	39	13	66.7
	0.63...0.8	18	47	17	63.8
Gravel+crushed claydite Гравий+дробленый керамзит	0.8...1.0	22	41	17	58.5
	1.0...1.2	13	45	12	73.3
	1.2...1.6	14	36	11	72.2
	1.0...1.2	15	46	14	70.5
	1.2...1.6	16	42	12	71.4
	1.0...1.2	19	44	13	70.5
	1.0...1.2	20	43	13	70.0
	1.2...1.6	22	39	12	69.2
	1.2...1.6	25	48	17	64.6
	1.2...1.6	27	42	16	62.0
	1.2...1.6	30	44	19	56.7
1.2...1.6	31	41	20	51.2	

Further studies to determine the maximum permissible values of filter cycles were carried out at constant speeds of 15 and 22 m/h, respectively, when using quartz sand with a grain fraction size of 0.8–1.0 mm and crushed expanded clay with a grain fraction size of 1.0–1.25 mm. It should also be noted that the average initial values of suspended solids when using crushed expanded clay were 42–43 mg/l, and when using quartz sand – 47–48 mg/l. In accordance with empirical data, the constructed curves are shown in Fig. 2.

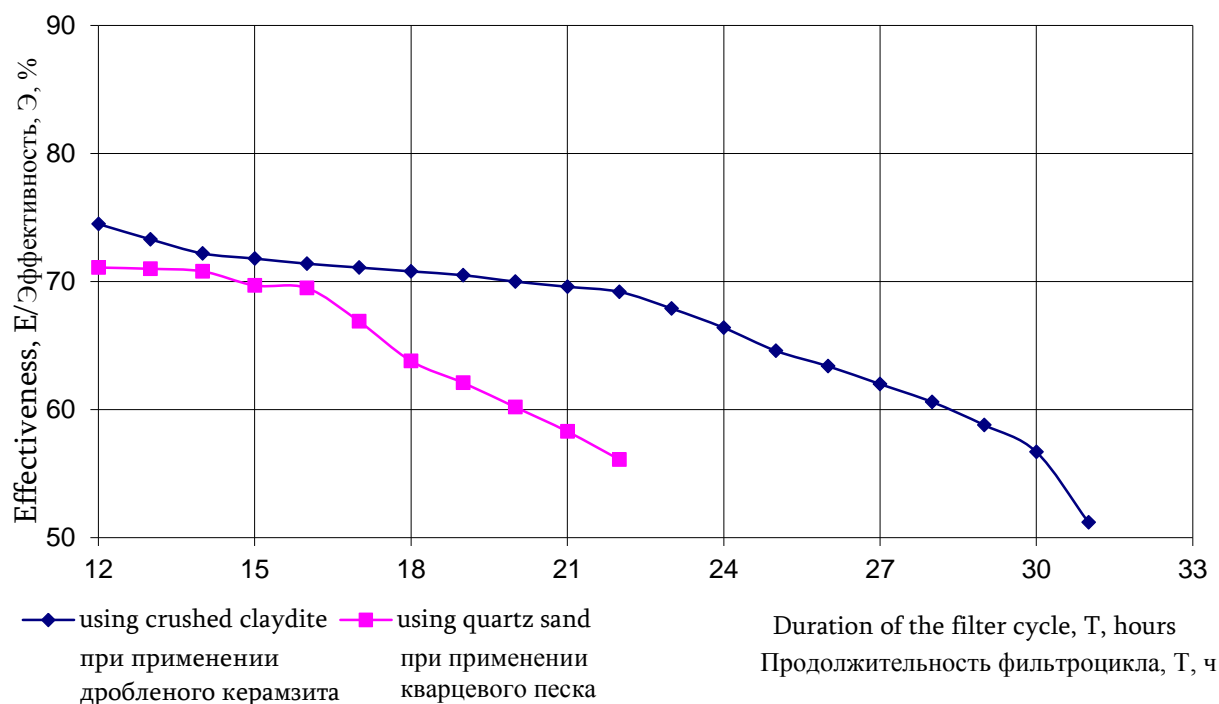


Fig. 2. Filtration duration effect on the efficiency of suspended substance retention

Рис. 2. Влияние продолжительности фильтрации на эффективность задержания взвешенных веществ

Table 3. Purification indicators for total knitted production runoff at the FFF

Таблица 3. Показатели очистки общего стока трикотажного производства на КЗФ

Main indicators Основные показатели	Filter medium, gravel+ / Фильтрующий материал, гравий+					
	quartz sand / кварцевый песок			crushed expanded clay / дробленый керамзит		
	min.-max. Values / мин.-макс. значения					
	before purification до очистки	after purification после очистки	E, %	before purification до очистки	after purification после очистки	E, %
Intensity of speed by breeding Интенсивность скорости по разведению	1:40–1:50	1:36–1:44	10...12	1:40–1:45	1:37–1:40	9...10
Suspended substances, mg/l Взвешенные вещества, мг/л	36–48	10–14	70,8...72,2	38...46	10...13	71,7...73,6
BOD _{full} , mg O ₂ /l БПК _п , мг O ₂ /л	135–170	81–100	40...41	140...168	95...97,4	39,2...42
COD mg O ₂ /l ХПК, мг O ₂ /л	240–260	168–180	30...32	240...250	168...173	30...30,8
Surfactants (SAS), mg/l nonionic ПАВ, мг/л неионогенные	11–16	9–13	18,2...22,0	12...18	10...15	16,7...20,0
	13–23	11–19	15,4...20	14...23	11,5...18,5	18...19,6

In parallel, for crushed expanded clay at a filtration rate of 15 m/h and for quartz sand at a rate of 12 m/h, analyses were also carried out to reduce the indicators of COD, BOD_{full}, nonionic, and anionactive surfactants. The results are shown in Table 3.

Results and discussions

Comparison of the efficiency of two filter media (Table 2) shows that if at filtration speeds of 12–15 m/h the use of crushed expanded clay provides a slight advantage over quartz sand, then at higher speeds

(16–22 m/h) the difference between these indicators only increases and specifically at a speed of 22 m/h reaches more than 10%.

In general, at high filtration rates, the use of crushed claydite provides more stability and efficiency. In particular, at speed of 19–22 m/h, almost the same effect is provided on the retention of suspended substances (70.5–69.2%).

According to the results of these studies, it can also be said that the maximum permissible filtration rate on the FFF, when using crushed expanded clay, can be

taken up to 27 m/h and when using quartz sand – up to 18 m/h.

According to the data obtained and available [6, 9, 18, 19], it can be said that the use of the FFF provides more stable purification with significant fluctuations in the initial values of suspended solids.

The use of crushed expanded clay provides more efficient purification by suspended solids, with their relatively high initial values (32–48 mg/l).

It follows from Table 2 that with relatively elevated initial values of suspended solids, the use of crushed expanded clay in the range of filtration speeds from 15 to 25 m/h provides a filter cycle duration of 30–24 hours, and at the same time the cleaning efficiency is 71.8–64.6%.

The relatively high filtration rates could not be significantly affected by the temperature regime, since the study was carried out indoors (at $20 \pm 2^\circ\text{C}$) and the viscosity of wastewater remained practically constant.

From the characteristic curves, shown in Fig. 2, it can be said that at initial concentrations of suspended solids of 42–48 mg/l, the maximum permissible duration when using crushed expanded clay can be taken up to 27–30 hours, and when using quartz sand – up to 20–22 hours.

This means that even with an initially higher filtration rate (22 m/h), the duration of the filter cycle when using crushed expanded clay is almost 1.5 times longer compared to quartz sand.

During the operation of the FFF installation, the retention of suspended substances was reduced sharply for longer than the specified filter cycles.

The research results shown that at extreme initial values (36–48 mg/l) of suspended solids, crushed expanded clay provides higher efficiency due to higher intergranular density. More angular shape of crushed expanded clay also has a beneficial effect on backfill washing, since the friction of the angular shape of crushed expanded clay grains is greater than the friction of the spherical shape of quartz sand grains.

From our point of view, it was the pronounced intergranular porosity (with a large grain shape coefficient) that allowed highly porous (66–74%) expanded claydite granules passing through a significant amount of wastewater at relatively high filtration rates. A slight reduction in washing time is explained by the greater friction of angular grains of crushed expanded claydite compared with spherical grains of quartz sand.

As the filter becomes dirty, the pressure loss increases, and the valve of the regulating device opens

wider, maintaining the set filtration rate. When the pressure loss in the filter is approximately 2.5 m, the filter material is backwashed. The washing clean water rises up through the filter material. Under the influence of the flow, the sand layer is agitated and significantly increases in volume, and its grains, being suspended in a turbulent water flow, are intensively cleaned as a result of friction against each other.

The laboratory unit was washed from bottom to top with tap water. With a grain size of 0.63–0.8 mm (0.8–1.0 mm) sand particles, the washing intensity was 10–12 $l/(s \cdot m^2)$, and with a grain size of 1.0–1.6 mm – 12–14 $l/(s \cdot m^2)$, the duration of washing quartz sand was 10–12 min., and for crushed expanded clay – 7–10 min.

Conclusions

Based on the results of the conducted research, the following conclusions can be drawn:

1. According to the data, given in Table 1, the average porosity of crushed expanded clay is 1.6 times greater than that of quartz sand, and the difference in the average coefficients of their shapes is 2.1–4.0 times. It is the pronounced intergranular porosity that will allow the expanded clay granules to pass through a significant amount of wastewater at relatively high filtration rates (20–22 m/h) and retain up to 70% of suspended solids (Table 2).
2. According to the characteristic curves, shown in Fig. 2, the duration of the filter cycle when using crushed expanded clay is at least 1.5 times longer than when using quartz sand.
3. Since the friction of angular grains of crushed expanded clay is greater than the friction of spherical grains of quartz sand, a more complete regeneration of the filtering properties of crushed expanded clay compared to quartz sand is provided 2–3 minutes earlier, regardless of the initial concentration of suspended solids.
4. According to Table 3, the filtering properties of crushed expanded clay during deep wastewater treatment of knitted production with the main concentrated pollution indicators (color intensity, BOD_{full} , COD and surfactant) are practically not inferior to the properties of quartz sand.
5. In order to obtain a more discolored and high-quality filtrate, a new series of studies should be conducted when using multilayer filters (with new highly porous filter materials) and when using various reagents.

REFERENCES

1. Mitin B.A. *Osobennosti konstruirovaniya i ekspluatatsii filtrov dlya ochistki promyshlennykh stokov* [Features of design and operation of filters for industrial sewage treatment]. Moscow, GPI Santekhproekt Publ., 1975. No. 2.
2. Uretskiy E.A., Subbotkin L.D., Moroz V.V. Experience of the recycled use of wastewater water at the enterprise of instrument- and machine-building. *Construction and industrial safety. Scientific and Technical Journal on Construction and Architecture*,

- 2018, vol. 63, no. 11, pp. 98–103. In Rus. Available at: <https://cyberleninka.ru/article/n/opyt-povtornogo-ispolzovaniya-stochnyh-vod-na-predpriyatii-priboro-i-mashinostroeniya/viewer> (accessed 28 March 2023).
3. Ayukaev R.I., Meltzer V.Z. *Proizvodstvo i primeneniye filtruyushchikh materialov dlya ochistki vody* [Production and application of filtering materials for water purification. Reference manual]. Leningrad, Stroyizdat Publ., 1985. 120 p. Available at: <https://elima.ru/books/?id=5627> (accessed 28 March 2023).
 4. *SNiP 32.13330.2018. Naruzhnyye seti i sooruzheniya* [SNiP 32.13330.2018. Outdoor networks and facilities]. Moscow, Minstroy of the RF, 2018. 72 p. Available at: <https://docs.cntd.ru/document/554820821> (accessed 28 March 2023).
 5. Moroz V.V. On the question of the dynamics of filtering lighting of suspensions on frame-filling filters. *Bulletin of the Brest State Technical University*, 2022, no. 1, pp. 37–41. In Rus. Available at: https://journal.bstu.by/index.php/bstu_herald/article/view/676/299 (accessed 28 March 2023).
 6. Shamyam V.L. Classification of fine-poros filling at frame-filling filtering. *Sbornik nauchnykh trudov YEGUAS*, 2009, vol. 34, no. 1, pp. 151–155. In Rus.
 7. Sidorova L.P. *Metody ochistki promishlennykh i stochnykh vod* [Techniques for purification industrial and waste waters]. Yekaterinburg, YFU Publ., 2012. P. I, 134 p. Available at: https://study.urfu.ru/Aid/Publication/11787/1/Sidorova_i_dr.pdf (accessed 28 March 2023).
 8. Frog B.N., Levchenko A.P. *Vodopodgotovka* [Water processing]. Moscow, MSU Publ., 2003. 680 p.
 9. Shamyam V.L., Mkrychev O.V. Opredeleniye konstruktivnykh parametrov karkasno-zasypnogo filtra [Determination of structure parameters of a frame-filling filter]. *Zhilishchnoye striotelstvo*, 1999, no. 12, pp. 14–15.
 10. Gogina E.S., Salomeev V.P., Pobegaylo Yu.P. Resolution of the problem of treatment of waste water generated by car washes and transport enterprises. *Safety of building systems. Ecological problems of construction projects. Geoecology. Vestnik MGSU*, 2012, no. 12, pp. 166–175. In Rus. Available at: <https://cyberleninka.ru/article/n/reshenie-problemy-ochistki-stochnyh-vod-ot-avtomoe-i-transportnyh-predpriyatii-1/viewer> (accessed 28 March 2023).
 11. Urmitova N.S., Abitov R.N., Nizamova A.Kh., Khabibullin R.R. The use of coarse coalescent materials in the units for oil field water treatment. *Water supply and sanitary technique*, 2018, no. 2, pp. 20–24. In Rus. Available at: <https://www.elibrary.ru/item.asp?id=32477331> (accessed 28 March 2023).
 12. Dovnar V.A., Tomson A.E., Sokolova T.V. Primeneniye torfyanykh sorbentov dlya ochistki stochnoy vody livnevoy kanalizatsii [Application of peat sorbents for waste water purification in storm drainage]. *Voda*, 2001, no. 5, pp. 22–23.
 13. Prodous O.A., Mikhailov A.V. The experience of using peat filtration for surface runoff treatment. *Water supply and sanitary technique*, 2019, no. 3, pp. 34–39. In Rus. Available at: <https://www.vstnews.ru/ru/archives-all/2019/2019-3/7500-opyt-primeneniya> (accessed 28 March 2023).
 14. Zaletova N.A., Voronov Yu.V. New technologies to solve the present-day challenges of waste water treatment. Technology of construction procedures. Mechanisms and equipment. *Vestnik MGSU*, 2012, no. 2, pp. 109–111. DOI: 10.22227/1997-0935.2012.2.109-111. Available at: <http://vestnikmgsu.ru/ru/component/sjarchive/issue/article.display/2012/2/109-111> (accessed 28 March 2023).
 15. Kalay E., Sarioglu H., Ozkul I. Design parameters of sand filtration systems in wastewater treatment process. *Advanced Engineering Science*, 2021, vol. 1, pp. 34–42. Available at: <http://193.255.128.114/index.php/ades/article/view/23> (accessed 28 March 2023).
 16. Samarpan Deb Majumder, Ankit Das. Development of a full-scale cost effective mango peel biochar-sand filter based wastewater treatment chamber in Patharpratima in West Bengal. *Ecological Engineering*, 2022, vol. 177, 106565. Available at: <https://doi.org/10.1016/j.ecoleng.2022.106565> (accessed 28 March 2023).
 17. Abdul Hamid N.H., Zulkifli N., Harun H., Mohamed Sunar N., Ali R., Hamidon N., Ahmad F. Production of nanocellulose filter paper for water purification from Malaysian sustainable forest resources (Shorea Roxburghii) through high-performance filtration in industrial wastewater treatment. *Progress in Engineering Application and Technology*, 2020, vol. 1, no. 1, pp. 116–126. Available at: <https://publisher.uthm.edu.my/periodicals/index.php/peat/article/view/96> (accessed 28 March 2023).
 18. Mohamed A.Y.A., Siggins A., Healy M.G., Fenton O., O'hUallach'ain D., Tuohy P. A novel hybrid coagulation-intermittent sand filter for the treatment of dairy wastewater. *Journal of Cleaner Production*, 2022, vol. 369, 133234. Available at: <https://doi.org/10.1016/j.jclepro.2022.133234> (accessed 28 March 2023).
 19. Wei Zhou, Pute Wu, Lin Zhang, Delan Zhu, Xining Zhao, Yaohui Cai. Heavy metal ions and particulate pollutants can be effectively removed by a gravity-driven ceramic foam filter optimized by carbon nanotube implantation. *Journal of Hazardous Materials*, 2022, vol. 421, no. 5, 126721. Available at: <https://doi.org/10.1016/j.jhazmat.2021.126721> (accessed 28 March 2023).
 20. Lima M.X., Carvalho K.Q., Passig F.H., Borges A.C., Filipe T.C., Azevedo J.C.R., Nagalli A. Performance of different substrates in constructed wetlands planted with *E. crassipes* treating low-strength sewage under subtropical conditions. *Science of The Total Environment*, 2018, vol. 630, pp. 1365–1373. Available at: <https://doi.org/10.1016/j.scitotenv.2018.02.342> (accessed 28 March 2023).
 21. Rusinova N.G., Samigullina G.Z. K voprosu o sovershenstvovanii tekhnologii ochistki stochnykh vod na energeticheskom predpriyatii [To the question of improving the technology of wastewater purification at the energy enterprise of the republic of Bashkortostan]. *Sovremennye voprosy mekhaniki sploshnykh sred* [Modern questions of continuum mechanics–2021]. pp. 152–160. Available at: <https://phsreda.com/e-articles/10353/Action10353-100731.pdf> (accessed 28 March 2023).
 22. Nimish Shah, Ankur H. Dwivedi, Shibu G. Pillai. Processes for the treatment of industrial wastewater. *Advanced Materials and Technologies for Wastewater Treatment*, 2021, pp. 285–316. Available at: <https://www.taylorfrancis.com/chapters/edit/10.1201/9781003138303-13/processes-treatment-industrial-wastewater-nimish-shah-ankur-dwivedi-shibu-pillai?context=ubx&refId=59a8f40e-0190-4f4c-9db6-a750c0b434f5> (accessed 28 March 2023).
 23. Shibly M.A.H., Tamanna TA. Efficient water utilization in knit dyeing factory of Bangladesh. *Journal of Textile Engineering & Fashion Technology*, 2020, vol 6, no. 3, pp. 71–75. DOI: 10.15406/jteft.2020.06.00232 Available at: <https://medcraveonline.com/JTEFT/JTEFT-06-00232.pdf> (accessed 28 March 2023).

24. Kravtsov A.M., Krugly V.F., Kruglaya E.A. Sovremennye filtruyushchie materialy dlya ochistki promlyivnykh stochnykh vod [Modern filtering materials for processing industrial waste waters]. *Agropanorama*, 2008, vol. 67, no. 3, pp. 41–46. Available at: https://rep.bsatu.by/bitstream/doc/1309/1/2008_3.13.sovremennye.pdf (accessed 28 March 2023).
25. Caliskaner O., Tchobanoglous G., Carolan A. High-rate filtration with a synthetic compressible media. *Water Environment Research*, 1999, vol. 71, no. 6, pp. 1171–1177. Available at: <https://onlinelibrary.wiley.com/doi/10.1002/j.1554-7531.1999.tb00199.x> (accessed 28 March 2023).
26. Shamyay V.L., Grazhdankina L.B. Povyshenie effektivnosti ispolzovaniya karkasno-zasypnogo filtra [Increasing the efficiency of using a frame-filling filter]. *Zhilishchnoe stroitelstvo*, 2002, no. 10, p. 31. Available at: http://rifsm.ru/u/f/js_10_02.pdf (accessed 28 March 2023).
27. Shamyay V.L. *Razrabotka tekhnologii glubokoy ochistki stochnykh vod predpriyatii khlopchatobumazhnoy promyshlennosti*. Avtoreferat Dis. Kand. nauk [Development of the technique for processing waste waters of enterprises of cotton industry. Cand. Diss. Abstract]. Moscow, 2000. 19 p. Available at: <https://www.disscat.com/content/razrabotka-tekhnologii-glubokoi-ochistki-stochnykh-vod-predpriyatii-khlopchatobumazhnoi-prom> (accessed 28 March 2023).

СПИСОК ЛИТЕРАТУРЫ

1. Митин Б.А. Особенности конструирования и эксплуатации фильтров для очистки промышленных стоков. Реф. сб. – М.: ГПИ Сантехпроект, 1975. – № 2.
2. Урецкий Е.А., Субботкин Л.Д., Мороз В.В. Опыт повторного использования сточных вод на предприятии приборостроения // *Строительство и техногенная безопасность*. Научно-технический журнал по строительству и архитектуре. – 2018. – № 11 (63). – С. 98–103. URL: <https://cyberleninka.ru/article/n/opyt-povtornogo-ispolzovaniya-stochnykh-vod-na-predpriyatii-priboro-i-mashinostroeniya/viewer> (дата обращения 28.03.2023).
3. Аюкаев Р.И., Мельцер В.З. Производство и применение фильтрующих материалов для очистки воды. – Л.: Стройиздат, 1985. – 120 с. URL: <https://elima.ru/books/?id=5627> (дата обращения 28.03.2023).
4. СНиП 32.13330.2018. Наружные сети и сооружения. – М.: Минстрой РФ, 2018. – 72 с. URL: <https://docs.cntd.ru/document/554820821> (дата обращения 28.03.2023).
5. Мороз В.В. К вопросу динамики фильтрационного осветления суспензий на каркасно-засыпных фильтрах // *Вестник Брестского государственного технического университета*. – 2022. – № 1. – С. 37–41. URL: https://journal.bstu.by/index.php/bstu_herald/article/view/676/299 (дата обращения 28.03.2023).
6. Шамян В.Л. Классификация мелкопористой засыпки при каркасно-засыпной фильтрации // *Сборник научных трудов ЕГУАС*. – 2009. – № 1 (34). – С. 151–155.
7. Сидорова Л.П. Методы очистки промышленных и сточных вод. – Екатеринбург: УрФУ, 2012. – Ч. I. – 134 с. URL: https://study.urfu.ru/Aid/Publication/11787/1/Sidorova_i_dr.pdf (дата обращения 28.03.2023).
8. Фрог Б.Н., Левченко А.П. Водоподготовка. – М.: Изд-во МГУ, 2003. – 680 с. URL: https://www.proektant.org/books/1996/1996_Frog_B_N_Levchenko_A_P_Vodopodgotovka_Uchebnoe_posobie_dlya_vtuzov.pdf (дата обращения 28.03.2023).
9. Шамян В.Л., Мкртычев О.В. Определение конструктивных параметров каркасно-засыпного фильтра // *Жилищное строительство*. – 1999. – № 12. – С. 14–15.
10. Гогина Е.С., Саломеев В.П., Побегайло Ю.П. Решение проблемы очистки сточных вод от автомоек и транспортных предприятий // *Вестник МГСУ*. – 2012. – № 12. – С. 166–175. URL: <https://cyberleninka.ru/article/n/reshenie-problemy-ochistki-stochnykh-vod-ot-avtomоек-i-transportnykh-predpriyatii-1/viewer> (дата обращения 28.03.2023).
11. Использование крупнозернистых коалесцирующих материалов в установках очистки нефтепромысловых сточных вод / Н.С. Урмитова, Р.Н. Абитов, А.Х. Низамова, Р.Р. Хабибуллин // *Водоснабжение и санитарная техника*. – 2018. – № 2. – С. 20–24. URL: <https://www.elibrary.ru/item.asp?id=32477331> (дата обращения 28.03.2023).
12. Применение торфяных сорбентов для очистки сточных вод ливневой канализации / В.А. Довнар, А.Э. Томсон, Т.В. Соколова и др. // *Вода*. – 2001. – № 5. – С. 22–23.
13. Продоус О.А., Михайлов А.В. Опыт применения технологии торфяной фильтрации для очистки поверхностных сточных вод // *Водоснабжение и санитарная техника*. – 2019. – № 3. – С. 34–39. URL: <https://www.vstnews.ru/ru/archives-all/2019/2019-3/7500-opyt-primeneniya> (дата обращения 28.03.2023).
14. Залетова Н.А., Воронов Ю.В. Новые технологии для решения современных задач очистки сточных вод. Технология строительных процессов. Механизмы и оборудование // *Вестник МГСУ*. – 2012. – № 2. – С. 109–111. URL: <http://vestnikmgsu.ru/ru/component/sjarchive/issue/article.display/2012/2/109-111> (дата обращения 28.03.2023).
15. Kalay E., Sarioğlu H., Özkul İ. Design parameters of sand filtration systems in wastewater treatment process // *Advanced Engineering Science*. – 2021. – V. 1. – P. 34–42. URL: <http://193.255.128.114/index.php/ades/article/view/23> (дата обращения 28.03.2023).
16. Samarpan Deb Majumder, Ankit Das. Development of a full-scale cost effective mango peel biochar-sand filter based wastewater treatment chamber in Patharpratima in West Bengal // *Ecological Engineering*. – 2022. – V. 177. – 106565. URL: <https://doi.org/10.1016/j.ecoleng.2022.106565> (дата обращения 28.03.2023).
17. Production of nanocellulose filter paper for water purification from Malaysian sustainable forest resources (*Shorea Roxburghii*) through high-performance filtration in industrial wastewater treatment / N.H. Abdul Hamid, N. Zulkifli, H. Harun, N. Mohamed Sunar, R. Ali, N. Hamidon, F. Ahmad // *Progress in Engineering Application and Technology*. – 2020. – V. 1. – № 1. – P. 116–126. URL: <https://publisher.uthm.edu.my/periodicals/index.php/peat/article/view/96> (дата обращения 28.03.2023).
18. A novel hybrid coagulation-intermittent sand filter for the treatment of dairy wastewater / A.Y.A. Mohamed, A. Siggins, M.G. Healy, O. Fenton, D. O'hUallach'ain, P. Tuohy // *Journal of Cleaner Production*. – 2022. – V. 369. – 133234. URL: <https://doi.org/10.1016/j.jclepro.2022.133234> (дата обращения 28.03.2023).
19. Heavy metal ions and particulate pollutants can be effectively removed by a gravity-driven ceramic foam filter optimized by carbon nanotube implantation / Wei Zhou, Pute Wu, Lin Zhang, Delan Zhu, Xining Zhao, Yaohui Cai // *Journal of Hazardous*

- Materials. – 2022. – V. 421. – № 5. – 126721. URL: <https://doi.org/10.1016/j.jhazmat.2021.126721> (дата обращения 28.03.2023).
20. Performance of different substrates in constructed wetlands planted with *E. crassipes* treating low-strength sewage under subtropical conditions / M.X. Lima, K.Q. Carvalho, F.H. Passig, A.C. Borges, T.C. Filippine, J.C.R. Azevedo, A. Nagalli // *Science of The Total Environment*. – 2018. – V. 630. – P. 1365–1373. URL: <https://doi.org/10.1016/j.scitotenv.2018.02.342> (дата обращения 28.03.2023).
21. Русинова Н.Г., Самигуллина Г.З. К вопросу о совершенствовании технологии очистки сточных вод на энергетическом предприятии // *Современные вопросы механики сплошных сред*. – 2021. – С. 152–160. URL: <https://phsreda.com/e-articles/10353/Action10353-100731.pdf> (дата обращения 28.03.2023).
22. Nimish Shah, Ankur H. Dwivedi, Shibu G. Pillai. Processes for the Treatment of Industrial Wastewater // *Advanced Materials and Technologies for Wastewater Treatment*. – 2021. – P. 285–316. URL: <https://www.taylorfrancis.com/chapters/edit/10.1201/9781003138303-13/processes-treatment-industrial-wastewater-nimish-shah-ankur-dwivedi-shibu-pillai?context=ubx&refId=59a8f40e-0190-4f4c-9db6-a750c0b434f5> (дата обращения 28.03.2023).
23. Shibly M.A.H, Tamanna TA. Efficient water utilization in knit dyeing factory of Bangladesh // *Journal of Textile Engineering & Fashion Technology*. – 2020. – V. 6. – № 3. – P. 71–75. DOI: 10.15406/jteft.2020.06.00232 URL: <https://medcraveonline.com/JTEFT/JTEFT-06-00232.pdf> (дата обращения 28.03.2023).
24. Кравцов А.М., Круглый В.Ф., Круглая Е.А. Современные фильтрующие материалы для очистки промливневых сточных вод // (УОБГАТУ). *Агропанорама*. – 2008. – № 3 (67). – С. 41–46. URL: https://rep.bsatu.by/bitstream/doc/1309/1/2008_3.13.sovremennye.pdf (дата обращения 28.03.2023).
25. Caliskaner O., Tchobanoglous G., Carolan A. High-rate filtration with a synthetic compressible media // *Water Environment Research*. – 1999. – V. 71. – № 6. – P. 1171–1177. URL: <https://onlinelibrary.wiley.com/doi/10.1002/j.1554-7531.1999.tb00199.x> (дата обращения 28.03.2023).
26. Шамян В.Л., Гражданкина Л.Б. Повышение эффективности использования каркасно-засыпного фильтра // *Жилищное строительство*. – 2002. – № 10. – С. 31. URL: http://rifsm.ru/u/f/js_10_02.pdf (дата обращения 28.03.2023).
27. Шамян В.Л. Разработка технологии глубокой очистки сточных вод предприятий хлопчатобумажной промышленности: автореф. дис. ... канд. техн. наук. – М., 2000. – 19 с. URL: <https://www.dissercat.com/content/razrabotka-tehnologii-glubokoi-ochistki-stochnykh-vod-predpriyatii-khlopchatobumazhnoi-prom> (дата обращения 28.03.2023).

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