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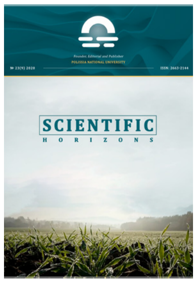

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Methods for Measuring the Optimal Time for the Water Residence in the Denitrification Filter

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Abstract. Nitrate filters are widely used in various sectors of the national economy for the purpose of stable degradation of nitrates without complex technological changes and control, as well as for obtaining, for practical use, water free from impurities of various polluting substances. The relevance of the stated research topic is determined by the wide use of filters in various areas of water conditioning in order to improve the quality of consumed water, as well as the need to develop methods for qualitative measurements of the optimal time parameters for the water residence in the denitrification filter when using it. The purpose of this research work is the practical development of methods for measuring the optimal time for the water residence in a denitrification filter, in order to find optimal opportunities for eliminating harmful and polluting substances from water used for domestic and industrial needs. The methodology of this research involves the use of a combination of methods for the systematic study of practical application issues of denitrification filters in water purification systems, using the method of qualitative analysis of water conditioning problems that are important with reference to the need to obtain high-quality water in volumes sufficient to meet the current domestic and industrial needs. The results of this research work are of great importance from the point of view of studying the problematic issues of determining the optimal time parameters for the water residence in modern filters, in order to achieve optimal indicators of the cleaning quality. The results and conclusions of this research are of considerable practical value for water filter designers, solving practical problems of creating high-quality denitrification filters, as well as for ordinary users, for whom the issues of water purification for its further practical application are of great importance

Keywords: aquarium, water conditioning, water purification, wastewater, biological filtration

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INTRODUCTION

The issues of measuring the optimal water residence in the denitrification filter are of considerable practical importance in terms of improving the quality of purification and the consumption of environmentally friendly products [1]. In the current state of the environment, the use of denitrification filters is essential, taking into account the need to obtain water purified from nitrates and its further use. Determination of the optimal time for the water residence in the denitrification filter is an important parameter from the point of view of calculating the indicators of water purification in general and the elimination of nitrates and other polluting substances from it, in particular. The holding time of water in the filter is essential in terms of the quality of its purification, which is extremely important for its subsequent practical use [2]. The issues of water purification and filtration have been studied relatively recently, while they are of considerable importance from the point of view of the state of the ecology of the environment, since water pollution with nitrates and other polluting substances has an extremely negative effect on both the general state of the environment and the prospects for the development of any of the spheres of the national economy in which there is a need for large volumes of purified water [3].

The currently existing technologies for industrial purification of filtration waters of various household waste landfills do not allow an objective assessment of the time required for water to stay in the types of filters used, from the point of view of achieving optimal quality parameters of such purification. At the same time, denitrification filters have recently become more widespread due to their ability to efficiently purify water from nitrates and other polluting substances. Denitrification involves the reduction of nitrates to gaseous oxides and molecular nitrogen, which is important, in particular, in aquaristics, since it is in this area that special attention should be paid to the preparation of water for its use in the aquarium, which requires bringing it to certain parameters [4]. Marine aquaristics involves the widespread use of denitrification filters, moreover, much earlier they were developed and successfully used for wastewater purification. In marine aquaristics, denitrification filters are widely used as part of a filtration system that includes several components. The main task of such devices is the transformation of nitrate into gaseous nitrogen with the help of special bacteria, which leave the aquarium complex during their evaporation.

Denitrification filters have the following operating principle: an oxygen-depleted environment, which contains denitrifying anaerobic bacteria, promotes the extraction of nitrates from oxygen. This happens as a result of a chemical reaction that can be carried out by many types of bacteria, including *Pseudomonas denitrificans, Pseudomonas aeruginosa, Paracoccus denitrificans, or Bacillus licheniformis* [5]. The main condition for the qualitative conduct of such reactions is a weak water inflow, which is no more than 30 liters per hour. A similar rate of water inflow is necessary to establish an anaerobic environment, since a more intense inflow causes a large volume of oxygen to penetrate into the inner space of the filter. Internal circulation in the filter contributes to a more uniform distribution of the anaerobic environment in its space, which, in turn, is necessary for the extraction and elimination of nitrates from the water.

The purpose of the work is the practical development of methods for measuring the optimal time for the water residence in the denitrification filter, in order to find the optimal possibilities for eliminating harmful and polluting substances from the water used for domestic and industrial needs.

MATERIALS AND METHODS

The methodology of the work consists of a combination of methods for systematic study of the issues of practical application of denitrification filters in water purification systems, with the method of qualitative analysis of water conditioning issues, which are important as part of the need to obtain purified water in those volumes that are sufficient to meet current domestic and industrial needs. A full-fledged research involves the study of the technical features of the denitrification filter designs and their operating principles in the implementation of the process of removing nitrates from water. In addition, the selected methods of scientific research combined provide the proper quality of the declared topic coverage due to its scientific and technical complexity and significance for industrial and domestic needs. The theoretical basis of this research work is the analysis of the scientific publications of researchers available within the framework of the stated topic of scientific research on the design of denitrification filters and their practical use in various industries.

In order to facilitate the perception of information and create an optimal, high-quality picture of scientific research, all the authors' developments from other countries, studied in the course of this scientific work and presented in the order of citation, were translated into Russian. The same was done in the section in which the results obtained in the course of this research work are compared with the results and conclusions of foreign researchers specialising in a wide range of issues raised in the subject of this research work or related to it. At the first stage of this research work, a theoretical study of the denitrification filter design features and their operating principle is carried out. This research stage also includes a systematic analysis of practical application issues of denitrification filters in water purification systems, which considerably complements and expands the overall scope of research.

At the second stage of this research work, the method of qualitative analysis of water conditioning issues was practically used, which are important as part of the need to obtain purified water in volumes sufficient to meet the current domestic and industrial needs. This research stage also included an analytical comparison of the obtained preliminary results with the results and conclusions of other researchers on the issues of determining the water residence time in the denitrification filter, which is optimal from the point of view of its high-quality purification. At the final stage of this research work, the final conclusions on the basis of the results obtained in the process were formulated, summing up the entire range of work performed within the framework of the declared topic, as well as highlighting the most essential research aspects. In general, the results and conclusions of this research work are a qualitative reflection of the entire complex of research carried out and can be effectively used during further research within the framework of the stated topic or related to it.

RESULTS

Denitrification filters play an important role in industrial wastewater purification in different countries and are widely used in the conversion of nitrates in water to nitrogen gas or nitrous oxide [6]. This process runs on the basis of the following chemical reaction:

$$5C + 4NO_{3-} + 4H + = 5CO_2 + 2N_2 + 2H_2O \quad (1)$$

In addition, carbon in the form of lactose is consistently added to denitrification filters, as well as beads used as filter fillers and containing recycled butyric acid in their base. The methods for measuring the optimum time for the water residence in the denitrification filter depend on the filter type and its operating principle. In this context, the following main types of denitrification filters used to remove nitrates from water should be highlighted:

– nitrate reducers used in aquariums with a volume of up to 1000 liters and containing in their design a large-volume reactor chamber, as well as a built-in pump for internal circulation;

– filters without internal water circulation, installed in containers of a relatively small volume (up to 150 liters), subject to intensive circulation and deaeration of water in the aquarium itself.

Taking into account the above, effective methods for measuring the optimal time for the water residence in the denitrification filter involve taking into account a number of parameters that are important from the point of view of the water purification quality:

– operating time of the filter during the release of nitrates and their impurities;

– water volume entering the inner space of the filter per unit of time;

– service life of the denitrification filter at the time of the purification;

– filter type.

The water volume entering the inner space of the filter per unit of time can be determined by the product:

$$V_в = S_г \times T \times V_c \quad (2)$$

where: $S_г$ – the filter throat area through which water enters; T – total time of water entering the filter; V_c – the rate at which water enters the filter.

Knowing the exact value of the water volume entering the denitrification filter during its operation, it is possible to calculate the water residence time in the filter, which is optimal from the point of view of purification quality of water samples. For this, the following ratio is used:

$$Tv = \frac{V_в}{S_в \times V_c} \quad (3)$$

where: $S_в$ – the area of the filter outlet through which the water leaves the filter.

The presented mathematical calculation model forms the basis of the dynamic adsorption method of water samples passing through the denitrification filter during its practical use. The essence of this technique is to perform a mathematical calculation of the dynamic indicators of water movement in the filter, taking into account all the accompanying factors [7]. The parameters of the optimal water residence time in the filter can vary depending on the rate of water entering the filter and the area of the inlet and outlet throats of the filter, which is affected by the specific design option. Figure 1 shows the dependence of the calculated parameter of the water residence time in the filter on the value of the filter inlet neck. Determination of the nature of the dependence under consideration is substantial from the point of view of finding ways to reduce the time value required for water to stay in the filter for its high-quality purification.

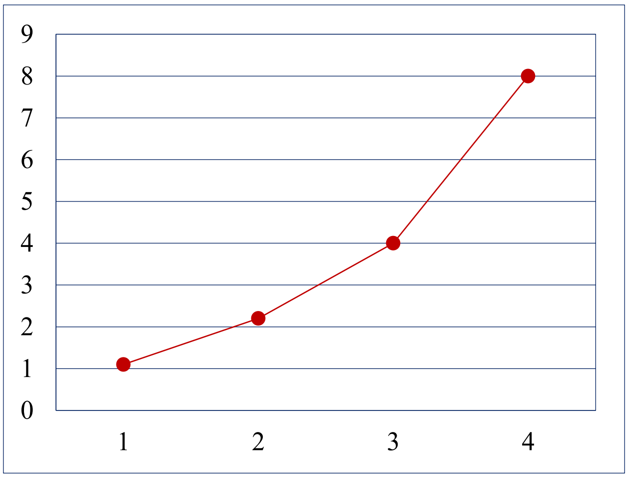

***Figure 1**. Dependence of the calculated parameter of the water residence time in the filter on the area value of the inlet neck of the filter*

In Figure 1, the X-axis shows the time (min) of water residence in the filter during purification, and the Y-axis shows the area of the filter inlet neck (cm^2), depending on its design. The data presented in Figure 1 indicate that there is a direct connection between the time required for optimal water purification in the denitrification filter and the inlet area through which water is supplied to the filter. This means that a constructive increase in the area of this hole automatically increases the time parameter required for high-quality purification of the water sample that entered the filter through its inlet neck. At the same time, the total volume of water entering the denitrification filter per unit of time also increases, and, therefore, the total volume of nitrates and polluting substances in the filter increases, which must be removed during water sample purification. The above technique is closely related to the comparative analysis method of water samples before and after purification. The practice of using comparative analysis implies the need for laboratory studies of the water quality before entering the filter and after its purification, in order to establish the optimal parameters for the water residence time in the filter, as well as taking into account the main design characteristics of the filter itself. This contributes to a more accurate determination of the amount of time required for the optimal purification from the point of view of the purification quality of the water sample entering the denitrification filter per unit of time.

At the same time, a change in the main design characteristics of the filter itself, as well as the volume of contamination of the water supplied to it, has a tangible effect on the reliability of the results of the comparative analysis, which indicates the relativity of the results obtained through its use and the high errors of its practical application [8]. Removing nitrates from aquarium water by filtering it is an alternative to cleaning aquariums by replacing the water, as well as planting special algae that consume nitrates and other substances in the aquarium water polluting it and preventing fish breeding. In this context, denitrification should be considered an oxidation process, and a denitrification filter is a device in which conditions are created for high-quality water purification entering it by methods of oxidation reaction. At the same time, the nitrates in the water gradually turn into nitrogen, harmless to the aquarium environment, which can be observed in the form of bubbles coming out. The process of sequential conversion of nitrates into nitrogenous compounds involves their sequential conversion into intermediate products: nitrites, nitric oxide, and nitrous oxide. In this case, one should take into account the fact that the multistage denitrification process presupposes the sequential development of a number of toxic products, including nitrites, in particular. Therefore, the need to determine the optimal water residence time in the denitrification filter is largely due to the need to create safe conditions for water purification and its subsequent use.

A high-quality solution to the issues of increasing the efficiency of the use of denitrification filters and carrying out denitrification in aquarium conditions, in general, suggests the need to control all stages of the denitrification process. Effective water filtration is impossible without proper maintenance of all denitrification process stages listed above. It is also required to bring the aquarium ecosystem to a state in which the accumulation of intermediate denitrification products will be completely excluded. The danger of the gradual accumulation of nitrites in the aquarium lies in the considerable pollution of the aquarium environment, as well as the real danger of creating conditions under which the very existence of fish in it will become impossible. The development of methods for measuring the optimal water residence time in the denitrification filter is a promising area of aquaristics and wastewater purification methods since it implies ample opportunities for improving the denitrification processes in general. These filter types have long been successfully used in saltwater aquariums and have recently begun to find widespread use in freshwater aquariums. Research in this area is far from complete and has broad prospects since the issues of effective cleaning of aquariums and wastewater are of great importance both for the functioning of industrial facilities and for ordinary citizens.

DISCUSSION

Changing the modes of wastewater supply helps to reduce the total amount of harmful substances entering the anaerobic zone of the denitrification filter, which negatively affects the purification process intensity. In such a situation, denitrification filters cannot compete with heterotrophs in terms of the rate of organic substances processing, as well as in water purification quality. In addition, the anaerobiosis conditions in the first, anaerobic zone, can be maintained to a much lesser extent, since this area contains not only nitrites and nitrates, but also oxygen dissolved in water [9]. Wastewater purification involves the elimination of the bulk of harmful impurities, as well as high-quality elimination of nitrates, phosphorus, and nitrogenous compounds. The procedure for such a purification involves the course of ammonification processes followed by nitrification and hydrolysis of phosphorus-containing compounds. At the same time, a large amount of these elements regularly enter natural water bodies, which determines the degree of their pollution and the need for regular purification [10]. Water filtration in an aquarium is a rather complex process, consisting of many sequential stages and involving the comprehensive use of mechanisms, both similar to natural methods of wastewater purification, and specially developed modern technological solutions. At the same time, specific filter manufacturers for water purification recommend certain purification methods for practical use, in accordance with the methods of using purifying substrates and filling cleaning filters [11].

In this case, it is implied that mechanical filtration should precede biological one since a sequential increase in the porosity of the filling substances is assumed. Correct filter filling presupposes the presence of a coarse-porous sponge in its lower compartment, while in some filter models there are special compartments or chambers that can be easily removed and designed to accumulate particularly large polluting substances. In addition, some filter models assume the presence in their design of special elements for the automatic elimination of this kind of contamination with a continuous water flow, which allows the filter to be flushed much less frequently. The coarse-pored sponge in the lower filter compartments of some manufacturers is combined with special ceramic rings, which are placed in a layer directly in front of it. The main purpose of such a structure is to evenly distribute the water flow throughout the entire available area, which contributes to the creation of vortex flows that can delay the water movement, slow down its rotation, resulting in the deposition of the largest possible amount of pollutants. In addition, after the coarse-grained sponge, a sponge with smaller pores can be structurally provided, followed by a padding polyester filler, whose function is to collect smaller particles of impurities [12]. Such a filter design implies a higher quality water purification from harmful impurities and pollutants.

The faster goes the process of biological oxidation of water when passing through the filter, the higher its temperature. Also, from the point of view of nitrates displacement quality, the percentage of oxygen in water is important and should not exceed 70% of the value of its maximum solubility in water at a fixed temperature value for the optimal course of the purification process. In this case, the optimal course of oxidative processes is ensured, since the presence of oxygen in the aquarium is essential not only from the point of view of the need for respiration of plants and fish but also for the high-quality course of biofiltration processes. Nitrified bacteria also need oxygen, and in large quantities [13]. The oxygen demand increases as the temperature and porosity of the substrate used in the filter increase. Oxygen consumption begins already from the first layers of filtration materials, and the rate of oxygen consumption directly depends on the degree of general pollution and the type of denitrification filter used. Nitrates are the end product of the decomposition of organic substances and for this reason, they are practically not removed from the water, gradually accumulating in it. This explains the fact that biological water filtration processes will never replace water changes. Periodic replacement of the aquarium water is in any case necessary, regardless of what kind of filtration system is provided in it.

With an average value of the total biomass of fish in the aquarium, there is a need to replace the aquarium water with fresh water, at least once a week, about a third of the total volume [14]. In the event that the water change stops in a natural reservoir, a swamp will appear in its place after some time. If the water in the aquarium does not change, it will deteriorate much faster than in a natural reservoir. Installing a biofilter does not guarantee immediate effects, the same applies to flushing or replacing it. High-quality filter operation takes time during which bacteria colonies take root and develop in it. Only then it begins to function at full capacity. The efficiency of denitrification filters is determined by the gradual increase in the number of bacteria. Provided that all the necessary conditions are met, this period will be from two to four weeks. Special techniques can help to shorten this period, which is achieved by adding some water from the soil from the old aquarium to the new one. Such procedures requires strict adherence to the principles of hygiene since it is quite easy to introduce new strains of bacteria into the aquarium, which greatly complicates the subsequent reservoir purification [15; 16]. There is often a situation in which some manufacturers' recommendations, declaring the correspondence of any filter to specific water volume in the aquarium, turn out to be unwarranted.

The most essential indicators in determining the feasibility of the practical use of denitrification and biological filters in an aquarium are the activity of fish in it, its total biomass, and the feeding frequency. If we are talking about an aquarium with living plants and relatively low biomass of living organisms, the minimum filter performance indicators are sufficient for a high-quality solution of all water purification tasks. In the event that large fish live in the aquarium and feed relatively often, there is a need to gradually increase the recommendations on the filter performance for purifying such a reservoir several times. Among all filter manufacturers, only Tetra is known for taking the total biomass of aquarium fish into account when calculating filter performance. The filter operating instructions from this manufacturer contain a lot of practical recommendations for keeping and feeding fish, as well as maintaining a high level of the aquarium's entire ecosystem. The optimal parameters of the water residence in the denitrification filter during purification are calculated in order to improve the water quality in the aquarium, as well as the wastewater used in industrial developments. The water residence time in the filter is essential from the point of view of water purification quality and the elimination of nitrate compounds from it.

Depending on the water residence time in the filter, the indicators of the total water purification in the aquarium are determined in the case of an aquarium filter and wastewater with filters of a different type. At the same time, these indicators have a direct impact on the total operating time of the filter, which is essential from the point of view of the duration of maintaining the high quality of water purification. The adsorption method, which involves the use of activated carbon, has become widespread in the process of aquarium water purification. At the same time, the value of activated carbon is somewhat overestimated, since it does not remove nitrates and nitrogen-containing ions from water. Activated carbon removes large organic molecules from water, as well as individual gases, peptides, and amino acids. Moreover, activated carbon is able to indirectly contribute to the elimination of activated nitrogen, since nitrite and ammonium are products of the decay of protein elements that retain carbon. The use of activated carbon in the aquarium water purification contributes to the water production with a very high degree of transparency, while the charcoal helps to heal fish and removes drugs dissolved in it from the water [17]. The method of aquarium water chemical filtration is used relatively rarely. In the meantime, ion exchange, synthetic resins, as well as minerals of natural origin belonging to the group of zeolites, are usually used as a filtration material.

The chemical filtration method leads to the absorption of nitrates, ammonium, phosphates by resins and zeolites, with the release of sodium ions, which are completely harmless from an environmental point of view. In addition, the definition of the chemical filtration method includes the use of high moor peat as filter media in purifying operations [18]. Peat provides light water acidification and contributes to the addition of biologically active substances. Such cleaning methods should not be combined with each other in the operation of the simplest filter. Films that appear as a result of a high concentration of bacteria and other biologically active substances can be due to using any substrate, while any biological filter is suitable for solving problems of high-quality water purification. At the same time, it is very difficult to develop such a filter design in which it would be impossible to place an insert, zeolite, or carbon. This is despite the fact that the bulk of large external filters are designed to solve complex issues of water regeneration. At the same time, the most common filtration method is biological filtration, in which industrial canister filters are actively used. There are many models of such filters and their varieties. These are mainly filter models with multiple filling layers, such as sponges, zeolites, and other solids [19].

Filters with special ceramics and other highly porous materials as a filler, a large number of pores of which is a favourable environment for bacteria that enter into a chemical reaction, are often used. The more pores in the filter, the more space for bacteria to reside, which qualitatively improves the performance of biological filtration. Methods for measuring the optimal water residence time in denitrification filters are constantly being improved, which determines the development of the industry of creating water purification facilities and contributes to the search for new, more effective ways to purify aquarium and wastewater. At the same time, there is a growing need for new, effective technologies for removing nitrates and harmful impurities from water, improving the water quality used for domestic and industrial needs [20]. The strengthening of this need leads to an intensive search for new opportunities to improve water filtration quality, as well as to the creation of new methods for the optimal water residence time in denitrification filters, which generally meets the needs for improving the quality of waste and aquarium water purification. In the future, the issues of improving the quality of water conditioning and water purification for domestic and industrial needs will not lose their relevance, which will lead to the discovery of new high-quality solutions to the issues considered in this area.

CONCLUSIONS

The optimal water residence time in the filter during purification must be calculated in order to accurately determine the optimal operating modes of the filter when it is in aquarium water or wastewater. This indicator is calculated taking into account the total time of the chemical reaction course for the nitrates elimination, which is described by the corresponding chemical formula. With the knowledge of the exact time required for the optimal elimination of nitrate impurities from the water, it is quite possible to accurately plan the procedure course for purifying an aquarium or wastewater for industrial purposes, which is essential from the point of view of their subsequent economic use. In addition, the water residence time in the filter during purification determines the nature of both the purification itself and the filter quality, since it allows making a preliminary calculation of the possible service life of the filter. Nitrates removal from water occurs as a result of a complex chemical reaction, the flow time of which is essential from the point of view of assessing the water residence time in the filter itself.

This time can be determined using various methods, the most effective of which are the method of dynamic adsorption of water samples and the method of comparative analysis of water samples before and after purification. These methods have approximately the same practical efficiency and can be successfully used in situations where it is required to determine the optimal water residence time in denitrification filters. Water purification quality has a determining impact from the point of view of the safety of its further use, therefore, determining the optimal water purification time in the context of assessing the effectiveness of a particular denitrification filter is essential for understanding the optimal operating conditions and overall service life. This is necessary for a qualitative assessment of the filter overall efficiency and the feasibility of its use in specific situations, implying the need to maintain high efficiency and water purification quality.

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Методи вимірювання оптимального часу утримання води у денітрифікаційному фільтрі

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Анотація. Нітратні фільтри широко використовуються в різних галузях народного господарства з метою стабільної деградації нітратів без складних технологічних змін та контролю, а також з метою одержання води для практичного використання, вільної від домішок різних шкідливих речовин. Актуальність зазначеної теми дослідження визначається широким використанням фільтрів у різних областях кондиціонування води з метою покращення якості споживаної води, а також необхідністю розробки методів якісних вимірювань оптимальних параметрів часу для утримання води у денітрифікаційному фільтрі за його використання. Метою цієї дослідницької роботи є практична розробка методів вимірювання оптимального часу перебування води в денітрифікаційному фільтрі з метою пошуку оптимальних можливостей для усунення шкідливих і забруднюючих речовин з води, що використовується для побутових та промислових потреб. Методологія цього дослідження передбачає використання комбінації методів для систематичного вивчення питань практичного застосування денітрифікаційних фільтрів у системах очищення води, з використанням методу якісного аналізу проблем кондиціонування води, що є важливими з огляду на необхідність отримання високої якості води в обсягах, достатніх для задоволення актуальних побутових та промислових потреб. Результати цієї дослідницької роботи мають велике значення з точки зору вивчення проблемних питань визначення оптимальних параметрів часу перебування води в сучасних фільтрах, з метою досягнення оптимальних показників якості очищення. Результати та висновки цього дослідження мають значну практичну цінність для розробників водяних фільтрів, які вирішують практичні задачі створення високоякісних фільтрів денітрифікації, а також для звичайних користувачів, для яких питання очищення води для подальшого практичного застосування мають велике значення

Ключові слова: акваріум, кондиціонування води, очищення води, стічні води, біологічна фільтрація