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Efficiency of using foamed glass for biofilter of an aquaculture recycling system

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Abstract. Modern technologies of cultivation of hydrobionts in recirculating aquaculture systems require significant volumes of biological filters (about 10% of the total volume of the fish farming system), which makes it relevant to search for new fillers that would have a larger specific surface area for colonisation by microorganisms than conventional polymer filling, which would reduce the size of the biofilter and, accordingly, the cost of water and electricity for the production of aquaculture products. The purpose of the study was to evaluate the effectiveness of using highly porous foamed glass as a biofilter filler, compared to conventional floating polymer loading. To achieve this goal, a systematic approach to a particular problem and general scientific research methods were used: experiment, modelling, comparison, analysis, synthesis, and generalisation. The model experiment was conducted in the educational and scientific laboratory of the Centre for Aquatic Bioresources and Aquaculture of the National University of Life and Environmental Sciences of Ukraine. Based on the results of the experiment, it was found that the test material has a significantly higher bio-cleaning potential than polymer loading for biofilters. The maximum concentration of ammonia in the water of the recirculating aquasystem for growing sturgeon fish, which is oxidised by a biofilter with 1 dm^3 of foamed glass as a filler (32 mg/dm^3) during the day, was determined. Calculations of the potential biological load during the cultivation of hydrobionts in the aquasystem were carried out, and it was found that 10 md^3 of this filler maintains an optimal level of nitrogen content when growing sterlet fish planting material with a planting density of 41.6 kg/m^3 or 84.8 kg/m^3 of commercial fish. It is determined that the required volume of the biofilter is reduced by 4.55 times, and the cost of water and energy supply for the operation of the recirculating aquasystem will also be proportionally reduced. Thus, the use of foamed glass as a filler for biofilters of recirculating aquasystems will increase the profitability of fish production at aquaculture enterprises

Keywords: fish farming, sterlet, process water, nitrifying bacteria, TAN oxidation

Introduction

Recirculating aquaculture systems, due to the rational use of water and land resources and a high level of intensification of the technological process, in contrast to pond fish farms, can be placed directly in large settlements, which are the centre of qualified personnel and services, have a developed infrastructure for the supply of raw materials and sales of finished products [1].

Conventional forms of fish farming and animal husbandry are sources of environmental pollution. The bulk of pollutants from growing fish in open aquasystems come together with discharge process water. The water contains the remains of artificial feed, faecal masses, and nitrogen-containing waste from the biochemical processes of fish digestion [1]. The main part of nitrogen (75-85%) is released through the gills of fish in the form of ammonium ions, which in high concentrations is dangerous for hydrobionts and accelerates the processes of eutrophication of water bodies [2]. In addition, in the natural reservoirs of areas where pond aquaculture enterprises are located, there is a risk of biological invasions of foreign species, and the spread of infectious and invasive diseases [3].

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To reduce the impact of aquaculture on the environment, so-called environmentally friendly technologies and production practices are used with the economical use of natural water and land resources and minimal waste in production. One of the forms of such technologies is the cultivation of hydrobionts in recirculating aquasystems [4].

The technology of operation of recirculating aquasystems involves controlling the parameters of the water environment. Systems with a full water regeneration cycle can capture from 96-100% of the resulting pollutants [5], depending on the volume of make-up water passing through the system. For comparison, a system with partial water reuse usually achieves an overall waste collection efficiency of 25-50% [6]. In addition, for the use of "Cornell" round fish tanks with double drainage and microporous filter [7; 8], recirculation systems produce a much smaller and more concentrated flow of waste, the disposal of which is much more efficient than in the operation of conventional pools [9-11].

Thus, systems of partial and fully recirculated water use offer such key advantages over conventional fish farming as the reduction of the need for land and water resources by more than 80% and an increase in the efficiency of waste capture to 80-100%.

To ensure the sustainable functioning of the aquasystem, recirculating aquaculture plants require a large amount of energy resources for the operation of numerous electrical equipment and mechanisms that ensure water circulation and maintain optimal parameters of the quality of the water environment: pumps, climate control and lighting systems, aeration and/or oxygenation devices, control and measuring devices, etc. In addition, the need for water replacement remains at a fairly high level: from 5 to 100% of the system volume per day. Improving the environmental safety of recycling systems and increasing the profitability of aquaculture production is possible by improving the methods of process water regeneration.

One of the objects of improvement is the technology of water purification in biofilters. Researchers from many countries are working on improving the design of biofilters to bring them to certain standards, namely, the impact on the efficiency of removing ammonia by a unit of volume of the biofilter or the specific area of the filler [12-14], study new fillers for biofilters [15-17], carefully investigate the influence of various biotic [18-20] and abiotic factors on the processes of oxidation of nitrogen substances [21-23].

The use of highly porous fillers for biofilters in fish farming has long been unprofitable due to the rapid loss of their main advantage – a high specific area per unit volume, as a result of slagging micropores with biofilm residues. An annual complete replacement of fillers was required, which, given their significantly higher cost compared to polymer fillers, made their use unprofitable. However, the use of the method of reducing highly porous fillers for biofilters with sodium hypochlorite [24] significantly extends their service life, with a complete replacement only after significant mechanical wear of the material, which opens up the potential for using such fillers and requires research on the possibility of their use, drawing up work schemes and determining maximum productivity.

The purpose of the study was to evaluate the effectiveness of using highly porous foamed glass as a filler for the biofilter of a recirculating aquaculture system when rearing young sturgeon fish, compared with conventional floating polymer loading for biofilters.

Materials and Methods

The study was conducted in September-October 2021 in the educational and scientific laboratory of the Department of aquaculture of the Centre for Aquatic Bioresources and Aquaculture of the National University of Life and Environmental Sciences of Ukraine, in two stages: experimental, computational and analytical. At the first stage, the maximum level of saturation with total ammonia nitrogen (TAN) of the process water of the experimental recirculating aquasystem for growing sturgeon fish was determined, which is oxidised in a biofilter with foamed glass during the day. The second stage involved calculations of the potential biological load of young sturgeon fish (using the example of sterlet) and commercial fish of aquasystems with two types of biofilter materials: foamed glass and polymer floating loading.

The material for the research was foamed glass of the JBL MicroMec brand as a filler for the biofilter of the recirculating aquasystem for growing sturgeon (on the example of sterlet).

Research methods are generally accepted in fisheries science: hydrochemical (to establish quantitative parameters of the quality of the aquatic environment), fishery (to calculate the values of the potentially possible load of the recirculating aquasystem with biological material of cultivation objects), and economic (to evaluate the effectiveness of experimental options) [25].

For the experimental stage, 4 model closed water supply installations were designed and installed, each of which consisted of a fish tank (aquarium with a volume of 100 dm^3) and water treatment systems. This system included:

1) mechanical filter – porous foam sponges connected to a circulation pump. The mechanical filter was cleaned manually, daily;

2) biological filter – plastic container with a working volume of 2 dm^3, located at the top of the aquarium and connected to the pump. The filler is in a volume of 1 dm^3, with a usable area of 1,600 m^2/dm^3 (the aerobic zone available for nitrifiers is 10%). The ratio of the volume of biofilter filler to the volume of water in the fish tank was 1 to 100. To supply water to the biofilter, a "MinJang NS F801" pump with a capacity of 1,200 dm^3/h, with an energy consumption of 15 W/h was used.

Aeration of water was carried out using a compressor, with the placement of sprayers both in the fish tank and in the biofilter. To maintain the optimal temperature, "Resun Sunlike 200" aquarium heaters with a power of 200 W/h with a temperature controller were used. The water temperature was maintained in the range of 24.6-25.7°C, optimal for the operation of biofilters. During the experiments, a planned water change was carried out daily.

A preparation containing a culture of nitrifying bacteria was used to start biofiltration processes at the working level. The establishment of biological equilibrium in the systems occurred in the presence of objects of cultivation – sterlet fry (*Acipenser ruthenus Linnaeus*) with an average body weight of 2.5 g/unit according to the planting density of 150 units/ m^2.

After the biological filters reached their operating capacity and equilibrium was established in the systems, the maximum possible amount of ammonium nitrogen that can be oxidised during the day in a biofilter made of 1 dm^3 of highly porous foam glass was checked. For this purpose, the systems artificially increased the content of nitrogenous compounds in water by applying a solution of ammonium chloride NH_4Cl, starting at a concentration of 2 mg/dm^3. The concentration of ammonia was increased daily: during the first week – by 1, the second – by 2, and the third – by 3 mg/dm^3, to the maximum value above which the biofilter no longer performed the main task – oxidation of ammonium compounds.

Before the experiment, young sterlets were removed from aquariums because the concentration of NH_3/NH_4+ in the water was specially raised above the maximum permissible level for the cultivation of sturgeon fish (2 mg/dm^3) [1].

The studies included regular monitoring of the main parameters of the quality of the aquatic environment: water temperature, hydrogen index, concentration of oxygen dissolved in water, and content of nitrogenous compounds. The water temperature and the concentration of oxygen dissolved in water were measured according to the methods of quality control of the aquatic environment generally accepted in fish farming, using an AZ-86021 (DO) thermoximeter, the hydrogen index and the concentration of nitrogenous compounds in the water were established using 2010-2021 TM Ptero© ready-made test systems. The duration of the experimental stage of the study was 21 days.

Evaluation of the efficiency of using foamed glass as a filler for the biofilter was carried out using the calculation and analytical method of fisheries science, by predictive determination of the potential volume of fish products grown in an experimental closed water supply installation and comparison of the obtained data with similar indicators for an aquasystem with a biofilter filled with classical plastic floating loading. Generally accepted equations for the design of recirculating aquaculture systems were used for calculations [4].

Results and Discussion

Progress of the experiment to find the maximum permissible concentration of ammonium compounds (based on the average data for 4 experimental closed water supply installations) in an aquasystem with a biofilter containing 1 dm^3 of foamed glass as a substrate for nitrifying bacteria is shown in Figure 1.

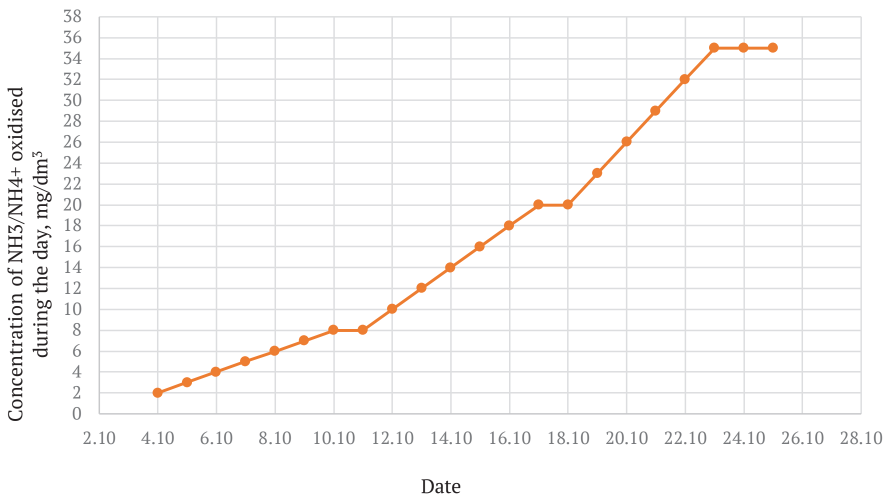

Figure 1. Dynamics of increasing concentration of NH_3/NH_4^+ in water during the experiment

As can be seen from the graph, the maximum concentration of ammonia (32 mg/dm^3), in process water with a volume of 100 dm^3, which can be oxidised by a biofilter with 1 dm^3 of foamed glass during the day was achieved on the 21st day of the experiment.

At the second stage of the study, the potential volume of biological load on the experimental aquasystem was first calculated.

The total ammonia nitrogen (TAN) ions entering the water during fish rearing in closed water supply installations was calculated from the mass of fish feed (Mf) that is applied during the day. The mass of TAN (MTAN) was determined considering the protein content in the feed (Cp, in tenths of a unit), as a nitrogen source, by the equation:

$$M_{TAN} = Mf * Cp * 0.092 \quad (1)$$

Accordingly, knowing the maximum value of M_{TAN}, which nitrifying bacteria can oxidise during the day in a biofilter with 1 dm^3 of foamed glass as filler (32 mg/dm^3 or 32 g/m^3), it is possible to set the amount of feed corresponding to TAN value by the equation:

$$Mf = \frac{M_{TAN}}{Cp * 0.092} \quad (2)$$

Aller Silver TM "Aller Aqua" product feed with a protein content of 45%, with a pellet diameter of 3 mm, intended for young sturgeon with an individual weight of 50-200 g, which were kept in experimental systems at the stage of launching biofilters, was taken for the calculation. Therefore, the value of Cp for calculation is 0.45.

As a result of the calculation, it was found that the biofilter filled with 1 dm^3 of foamed glass as a substrate for nitrifying bacteria can provide TAN oxidation, which corresponds to 77.3 g of mixed feed. This amount of feed will provide the daily nutrient requirement for 4.16 kg of sterlet planting material, while the daily feeding rate of this fish is 1.86% of its total weight in a system with a working volume of 100 dm^3. Accordingly, a biofilter filled with foamed glass in a volume of 10 dm^3, will provide biological purification of 1 m^3 process water in which young sterlet with a total weight of 41.6 kg can be kept.

A similar calculation was made for aquasystems that grow commercial sturgeon fish with an individual weight of 0.5 to 2.0 kg/unit on Aller Silwer mixed feed (granule diameter – 8 mm, protein content – 41%), with the recommended daily feeding rate – 1% of fish body weight. It is established that 10 dm^3 of foamed glass in a biofilter can provide biological purification of 1 m^3 of process water for the content of 84.8 kg of commercial sturgeon fish in this volume.

The value of the biological load of commercial sturgeon fish on the aquasystem obtained in the calculations corresponds to scientific data on the maximum permissible biological load of the recirculating aquasystem for sturgeon fish. Thus, according to experimental data, the biomass of commercial sturgeon fish can be increased to 83 kg/m^3, provided that the process water of the recirculation system maintains a sufficient concentration of dissolved oxygen.

By increasing the size of the biofilter and, accordingly, the amount of filler, in the proportion of "biofilter volume: total water volume in the aquasystem", it is theoretically possible to achieve an increase in fish productivity. In this case, the maximum actual value of this indicator will depend on the biological characteristics of the cultivated object and on the ability to meet its requirements for living conditions.

Further calculations concerned the determination of the volume of classical floating polymer loading for a biofilter capable of oxidising 32 g of ammonia in 1 m^3 of process water during the day. Standard capacity of 1 m^2 of the surface of such a substrate, at a water temperature in the range of 21-24°C – 1 g of TAN per day [1]. Therefore, the required surface area of the substrate is 32 m^2. For Helix White 12x12 filler, with a specific substrate surface area of 704 m^2/m^3 which is popular at fish farming enterprises in Ukraine, the loading volume for the biofilter will be 45.5 dm^3. Wholesale price of such filler – 28,500 UAH/m^3, therefore, the cost of purchasing a floating polymer filler for a biofilter will amount to UAH 1,296.75.

To purchase 10 dm^3 of highly porous foamed glass, required for oxidation of 32 g of ammonia per day, at a wholesale price of 246 UAH/dm^3, it is necessary to spend UAH 2,460. However, the operational period for floating polymer loading does not exceed one year, after which a complete replacement of the biofilter filler is required, and the JBL Micromec foam glass is a strong inorganic material that is practically not subject to mechanical wear. The manufacturer of this biofilter filler is JBL GmbH & Co. KG (Germany) guarantees an unlimited period of use of the material.

As evidenced by practice, when using foamed glass as filler for biofilters, there is a need for periodic, once every two months, deep cleaning of the filler pores from outdated biofilm with chemical reagents, in particular, sodium hypochlorite [24]. For the restoration of 1 m^3 of filler, it is necessary to spend 26.3 litres of grade "A" sodium hypochlorite with a concentration of active chlorine of 19%, for a total amount of UAH 733.42. Thus, the cost of cleaning 10 dm^3 of filler 6 times a year will amount to UAH 44.01, which together with the cost of filler will be UAH 2,504.01.

When comparing two types of biofilter filler with a daily ammonia oxidation capacity of 32 g/m^3 according to the indicator of purchase and operation costs (2,504.01 UAH/year – foamed glass, 1,296.75 UAH/year – floating polymer loading), it becomes obvious that the use of foamed glass will pay off in two years. The proposed method of increasing the efficiency of biological treatment of process water in recirculating aquaculture systems allows not only to improve the quality indicators of filtration systems, as proposed in similar studies using new developments of biological fillers [15-17], but also requires a smaller 4.55 times the volume of this filler, compared to the classic one, and, as a result, would require a smaller size and, accordingly, cheaper in the manufacture of biofilters, and would lead to a decrease in the total volume of water in the system and reduce energy costs associated with water circulation and thermoregulation.

Moreover, the use of highly porous fillers as a filler for biofilters does not require the installation of additional specific equipment or the use of consumables to stimulate nitrification processes in comparison with other studies [19; 23]. Separately, there is no need to make significant changes to the design of the biological filter, which is currently most often used in recirculation systems both in Ukraine and in the world, for the use of the proposed fillers, except for a significant reduction in the required volume.

Conclusions

Based on the findings, the following was established:

1. Maximum concentration of TAN that can be oxidised in a 100 dm^3 fish tank by a biofilter filled with 1 dm^3 of foamed glass, is 32 mg/dm^3. This value corresponds to the level of biological load of the aquasystem for young sterlet – 41.6 kg/m^3 and for commercial fish – 84.8 kg/m^3, and does not exceed the technological standards for growing sturgeon fish in recirculating aquaculture systems.
2. The payback period for highly porous foamed glass as a biofilter filler, compared to the classic floating polymer loading, is two years. In addition, due to the smaller size of the biofilter, the cost of water and energy supply to the aquasystem will be reduced.

It is promising to continue research on highly porous foamed glass as a filler for the biofilter of the recirculating aquasystem in the line of increasing the efficiency of using the useful area of the substrate of this material by nitrifying bacteria.

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Ефективність використання спіненого скла для біофільтру рециркуляційної системи аквакультури

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Анотація. Сучасні технології культивування гідробіонтів у рециркуляційних системах аквакультури потребують значних об'ємів біологічних фільтрів (близько 10 % від загального об'єму рибницької системи), що робить актуальним пошук нових наповнювачів, які матимуть більшу, ніж у традиційного полімерного завантаження, питому поверхню для заселення мікроорганізмами, що дозволить зменшити розміри біофільтру і, відповідно, витрати води та електроенергії на виробництво продукції аквакультури. Метою дослідження була оцінка ефективності використання високопористого спіненого скла в якості наповнювача для біофільтру, у порівнянні з традиційним плаваючим полімерним завантаженням. Для досягнення мети використано системний підхід до визначеної проблеми і загально-наукові методи дослідження: експеримент, моделювання, порівняння, аналіз, синтез та узагальнення. Модельний експеримент проведено у навчально-науковій лабораторії Центру водних біоресурсів та аквакультури НУБіП України. На підставі результатів експерименту було встановлено, що досліджуваний матеріал має значно вищий біоочищувальний потенціал, ніж полімерне завантаження для біофільтрів. Визначено максимальну концентрацію аміак-амонію у воді рециркуляційної аквасистеми для вирощування осетрових риб, яку протягом доби окислює біофільтр із 1 дм^3 спіненого скла у якості наповнювача (32 мг/дм^3). Проведено розрахунки потенційно можливого біологічного навантаження при культивуванні гідробіонтів в аквасистемі, та встановлено, що 10 дм^3 зазначеного наповнювача підтримують на оптимальному рівні вміст азотних речовин при вирощувані рибопосадкового матеріалу стерляді за щільністю посадки 41,6 кг/м^3 або 84,8 кг/м^3 товарної риби. Визначено, що необхідний об'єм біофільтра зменшується у 4,55 разів, пропорційно скоротяться й витрати на водо- та енергозабезпечення роботи рециркуляційної аквасистеми. Отже, використання спіненого скла в якості наповнювача для біофільтрів рециркуляційних аквасистем підвищить рентабельність виробництва рибної продукції на підприємствах аквакультури

Ключові слова: рибництво, стерлядь, технологічна вода, бактерії-нітрифікатори, окислення TAN