Features of the water treatment technology of fish breeding plants in the southern region of the Russian Federation using agricultural waste

Nikolai Serpokrylov\textsuperscript{1,}\textsuperscript{*}, Alla Smolyanichenko\textsuperscript{1,2}, and Sergei Starovoitov\textsuperscript{1}

\textsuperscript{1}Don State Technical University, 1, Gagarin Sq., 344003, Rostov-on-Don, Russia
\textsuperscript{2}The State Maritime University named after Admiral F.F. Ushakov, 8, Sedova St., 344006, Rostov-on-Don, Russia

Abstract. One of the main reasons for the decline in fish numbers is the insufficient quality of water used in hatcheries. The degree of purification of recycled water does not meet the requirements for water in pools. Thus, in order to reduce pollution concentrations, it is necessary to develop new technologies for the treatment of recycled water from fish farming plants, including through the integration of a lighting and aeration plant into them, as well as a sorption unit using agricultural waste, namely rice straw.

1 Introduction

Ichthyologists found that as a result of the life of aquatic organisms of fish disease, their survival is correlated with the content of ammonia and ammonium ions in the water. The accumulation of reduced forms of nitrogen to 0.4–0.6 mg/L and higher, the increase in permanganate oxidation to 20 mgO2/l, and the bichromate oxidation to 40–60 mg O2/l occurs as a result of the excretion of aquaculture, mass development and subsequent death of phytoplankton due to excessive density of fish landing, feed application without regard to their needs. And this, in turn, reduces fish survival by 23–40% [1].

To remove pollution from the waters of industrial fish breeding enterprises, biological, chemical and physico-chemical methods are used [2].

The effectiveness of water treatment processes depends on many factors, most of which are subject to change and regulation over a wide range [3,4]. One of these factors is lighting [5].

As you know, the forms of radiant energy are: sunlight, ultraviolet rays, X-rays, radioactive radiation, ultrashort radio waves. The effectiveness of various rays depends on the dose. In addition, a very significant role is played by the wavelength, the permeability of the medium, the intensity and duration of irradiation. Small doses of radiation can even activate certain vital functions of microbial cells (for example, cell growth, metabolism). High radiation doses, as a rule, are lethal.

Therefore, it is necessary to establish the effect of lighting on the fish breeding process.

Today, fish farming enterprises with a closed water supply system are widely used, and the use of biofilters is the most common way to treat water from aquaculture growing systems.
facilities in closed-water installations [6-9]. However, at the outlet of the circulating water from the biofilter, the standard indicators for ammonia are not provided. In addition, the launch of biofilters requires at least 2 months, which, in conditions of temporary formation of nitrogen pollution, complicates the operation.

From the above it follows that an important area of research is the selection of energy-saving light sources and the development of technical solutions for lighting biomass in biofilters.

The main criteria for choosing lighting sources were power consumption, luminous flux and color temperature.

The color temperature (Figure 1) of LED and fluorescent light sources is in the range from 3800K (warm light) to 4500K (cold light), and depends on the spectrum of the emitted light and wavelength.

![Fig. 1. Color temperature (CT) of lighting elements.](image)

In addition to the influence of illumination, the article also examines the results of a study of the possibility of using recycled water in filtering plants as a filter load of rice straw, which is a waste of the agricultural industry.

Thus, the development of new methods for the treatment of recycled and waste water, the separation of fishery, including the use of agricultural waste, is a wasteful [10-13].

2 Materials and Methods

The object of the study was a private fish farm located in the city of Shakhty and engaged in catfish breeding.

At the fish farm there are 4 pools with a volume of 4.5 m³ each. The volume of circulating water is 21 m³. The capacity of the fish farm is about 700 kg of fish per month.

The scheme of recycled wastewater of a fish-breeding enterprise works on the principle of installing closed water supply (CWS), and is presented in Figure 2.
Fig. 2. Scheme of treatment of circulating wastewater from a private fish-breeding enterprise in the city of Shakhty.

The water treatment system works as follows: from pools with fish 1, wastewater flows into a mechanical drum strainer 2, where solid particles and part of the colloidal substances are retained. After the mechanical cleaning filter 2, tanks 3a were installed with static loading with plastic "honeycombs" and loading at 80%, and 3b with a floating loading, which act as a biological treatment filter. The area of honeycombs is 230m$^2$. The catfish excretion of dissolved nitrogen is 0.478 kg/day [14]. The volume of loading is 1.5 m$^3$.

Compressed air for aeration of the algobacterial mixture is supplied to the biological cleaning filter with the help of a blower 4, through dispersants 5 [15,16]. Further, the treated wastewater enters the sump 10, where activated sludge is collected into the denitrifier 9. Using a circulation pump 6, the wastewater from the sump 10 is returned to the fish pool 1 through the heat exchanger 7 to maintain the required temperature.

The existing recycling water treatment scheme at the fish farm provides a reduction of chemical oxygen demand (COD) by 50%, and biological oxygen consumption (BOD) by 5% (table 1).

The effectiveness of the existing circulating wastewater treatment scheme is insufficient for intensive fish farming. The necessary water flow to maintain favorable conditions for the content of catfish is 9 m$^3$/hour. Low cleaning efficiency is due to the development of microorganisms in accumulated activated sludge, as well as biomass on a floating load with insufficient lighting, or its absence. The air supply for aeration is excessive, which contributes to the raising of activated sludge from the bottom of the biofilter and its removal further through pipelines to the pool with fish and, as a result, increased turbidity of the water. Irritability was observed in fish, its low activity, low intensity of nutrition, and, as a result, a slow increase in the mass of fish.

During operation, the biological treatment system was supplemented with a denitrification unit - from the biofilter with a circulation pump 8, part of the wastewater flowed to the denitrification unit 9, after which it returned to the system in front of the mechanical filter (table 1).

According to the results of the analysis (table 1), after introducing into the technological scheme of biological treatment of recycled water the COD denitrification unit decreased by 89% compared to the initial concentrations, nitrates - 39.9%, which shows the effectiveness of the measures taken.
Table 1. Selected wastewater quality indicators at the outlet of the pool, after biofilter and after denitrification.

<table>
<thead>
<tr>
<th>Source</th>
<th>pH</th>
<th>COD. mgO₂/l</th>
<th>O₂. mg/l</th>
<th>NH₄⁺ - N mg/l</th>
<th>NO₂⁻ - N mg/l</th>
<th>NO₃⁻ - N mg/l</th>
<th>PO₄³⁻ - P mg/l</th>
<th>BOD. mgO₂/l</th>
<th>SS. mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>At the exit of the pool</td>
<td>7.0</td>
<td>860.0</td>
<td>5.4</td>
<td>0.420</td>
<td>0.87</td>
<td>158.0</td>
<td>9.1</td>
<td>80.0</td>
<td>99.5</td>
</tr>
<tr>
<td>After biofilter</td>
<td>7.3</td>
<td>430.0</td>
<td>5.6</td>
<td>0.050</td>
<td>0.15</td>
<td>142.0</td>
<td>8.7</td>
<td>76.0</td>
<td>58.5</td>
</tr>
<tr>
<td>with denitrification</td>
<td>-</td>
<td>94.0</td>
<td>3.6</td>
<td>0.050</td>
<td>0.18</td>
<td>95.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

To increase the efficiency of biological treatment, as well as reduce the cost of denitrification, a lighting and aeration unit was integrated into the biofilter (Fig. 3), connected to a 12-volt power supply and two Barbus air compressors with a power of 2.5 W and a capacity of 3 l / min each, for aeration of the treated wastewater and cooling the LEDs (Fig. 4).

**Fig. 3.** A modernized scheme for treating recycled wastewater of a private fish-breeding enterprise in the city of Shakhty with an installed lighting and aeration installation: 1 - fish pools, 2 - a mechanical drum strainer, 3 - biofilter containers (a - with a static load, b - with a floating load), 4 - blower, 5 - dispersant, 6 - circulation pump, 7 - heat exchanger, 8 - circulation pump, 9 - denitrification unit, 10 - sump with activated sludge intake.

To analyze the efficiency of the lighting and aeration installation, the calculation of the illumination in the biofilter was performed. The optical density of the wastewater was 0.02 after the pools, and 0.011 after the biofilter. The design of the lighting and aeration installation includes 240 LED elements with radiation of 13.3 Lm / pc.

Air is supplied to the lighting and aeration unit using a compressor and a voltage of 12 volts. Through the aeration tube 2 through the aeration spray-dispersant 5, air is distributed through the chlorella cultivator, thereby oxidizing the organic matter and sparging the medium. Air rises to the surface, thereby preventing it from fouling with a film of photosynthetic microorganisms, and leaves the environment.
The light in the lighting and aeration system of the blue and red spectrum that emits, enclosed in a housing of light-transmitting material 4, LED strip 3. In the process, due to temperature differences, condensation forms on the housing 4, between the LED strip 3 and the cultivated medium, which accumulates at the bottom of the device 6.

The accumulated condensate will lead to a short circuit and failure of the elements of the LED strip 3. To prevent condensation from accumulating at the bottom of the unit 6, a second tube is installed in the unit 4 for ventilation of the unit 1, through which air is supplied by a 2.5 Watt Barbus compressor and with a productivity of 3 l/min, moves to the lower part of the case.

Only 25-30% of the electrical energy consumed by the LED elements is converted into light, the rest of the energy goes to ultraviolet and infrared radiation, i.e. transforms into thermal energy.

Passport characteristics of the LED strip - 60 LED elements / 1 meter length, 12-14.4 W/m, 800 Lm/m, LED scattering angle 120: The length of the LED strip used as a light source is 4.3 m, i.e. The tape includes 260 LED elements, its power is 54.6-61.42 W, 3440 Lm.

Lighting and aeration installation was installed in the center of the biological filter tank. The volume of the biofilter was at a size of 1x1.4x1.1 (axbxc) = 1.55 m³. The body of the biofilter is 55% filled with floating biomass carriers. From this it follows that 45% of the lighting and aeration installation located in the near-bottom zone freely emits light to the bottom activated sludge, as well as to a layer of floating biomass carriers.

To increase the efficiency of removing ammonia nitrogen from the circulating waters of the fishery complex, the ability of rice straw to absorb contaminants was also studied.

To test the operation of the sorbent from rice straw on real circulating water, an experimental installation for filtering water was created, shown in Figure 5.
The principle of operation of the pilot plant was that water is supplied from fish breeding tanks 6 to an intermediate pressure tank 9, from which it enters the first purification stage, which is a micro-grid unit 1, the filtering element of which is a Betamesh 75 mesh selected on the basis of studies presented in the fourth chapter. Then the water enters the clarification filters 2 loaded with crushed rice straw. And then the water was filtered through filters 3, 4, into which various loads were poured, namely:

1) rice straw after NaOH activation and carbonization in a muffle furnace;
2) rice straw after activation of KOH and carbonization in a muffle furnace;
3) rice straw after activation of NaOH without carbonization;
4) rice straw after activation of KOH without carbonization.

The pilot plant consisted of 6 glass pipes with an inner diameter of 55 mm, an outer 65 mm and a height of 900 mm, open at the top, the lower part of the pipes was covered with a lid, of which two airtight exits were provided: the first is designed to supply water to the next stage purification, the second - for quality control and sampling.

Table 2 summarizes the results of studies of six variants of water purification technology in a laboratory installation using a Betamesh 75 mesh, rice straw as a filtrant and as a sorbent.

<table>
<thead>
<tr>
<th>Scheme 1</th>
<th>Types of materials</th>
<th>Filter dimensions</th>
<th>Pressure, s m</th>
<th>Material weight, g</th>
<th>Density, kg/m³</th>
<th>Speed equation filtering</th>
<th>Filtration speed (m³/m².h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Grid Betamesh 75</td>
<td>Round mesh D = 55 mm</td>
<td>6.5</td>
<td>-</td>
<td>-</td>
<td>y = - 0.0026x + 6.1854; R² = 0.7696</td>
<td>6.05</td>
</tr>
<tr>
<td>B</td>
<td>Rice straw without treatment</td>
<td>D = 5 sm. H= 10 sm</td>
<td>12</td>
<td>12</td>
<td>59.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Rice straw after NaOH activation and freezing (PC3NaOH)</td>
<td>D = 5 sm. H= 10 sm</td>
<td>1</td>
<td>11</td>
<td>56.05</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Regime parameters of technological systems of water purification using rice straw.
3 Results

In accordance with the conclusion obtained about the optimal placement in terms of illumination (Fig. 3), the aeration and lighting installation was integrated into a biological filter and put into operation under experimental industrial conditions for treating recycled water from a fish farm.

During the cleaning process, the biomass carriers are mixed and moved through the biofilter due to the supply of compressed air to aeration. Thus, biomass carriers floating in close proximity to the ALE are an obstacle to illuminating distant biomass carriers, as well, mixing and briefly absorbing a large dose of light, they follow the biofilter, providing the microorganisms with a day-night cultivation cycle.

Analyzing the results of table 5.3, we can conclude that the separation of the biological reservoir into two parts (part with mixing and air supply, part with additional light) allowed to reduce the concentration of COD and BOD, but also reduced the efficiency of the removal of ammonium nitrogen.

A month after the installation of the lighting and aeration installation, wastewater samples were taken and sent for analysis to an accredited laboratory. According to the results of the analysis (table 3), there is a decrease in COD by 90%, and BOD by 81% [12].

The obtained results against the background of purification by denitrification prove the rationality of using a lighting and aeration installation. The power consumption of the lighting and aeration installation was 63 W/hour, which is not inferior in cost to the cost of denitrification.

Analyzing the results obtained, it can be seen that the operation of the aeration and lighting installation increases the efficiency of water purification according to standardized ingredients compared to its absence (table 4).
Table 3. Indicators of recycling water treatment under industrial conditions for the main elements harmful to fish (mg/l).

<table>
<thead>
<tr>
<th>Source</th>
<th>pH</th>
<th>COD. mgO₂/l</th>
<th>O₂. mg/l</th>
<th>NH₄⁺. mg/l</th>
<th>NO₂⁻. mg/l</th>
<th>NO₃⁻. mg/l</th>
<th>PO₄³⁻. mg/l</th>
<th>BOD. mgO₂/l</th>
<th>SS. mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 At the exit from the pool</td>
<td>7.0</td>
<td>860.0</td>
<td>5.4</td>
<td>0.42</td>
<td>0.87</td>
<td>158.0</td>
<td>9.1</td>
<td>80.0</td>
<td>99.5</td>
</tr>
<tr>
<td>2 After biofilter</td>
<td>7.3</td>
<td>430.0</td>
<td>5.6</td>
<td>0.05</td>
<td>0.15</td>
<td>142.0</td>
<td>8.7</td>
<td>76.0</td>
<td>58.5</td>
</tr>
<tr>
<td>3 From the pools</td>
<td>-</td>
<td>530.0</td>
<td>6.2</td>
<td>2.34</td>
<td>0.60</td>
<td>218.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4 After biofilter</td>
<td>6.4</td>
<td>88.0</td>
<td>7.4</td>
<td>2.90</td>
<td>0.50</td>
<td>189.0</td>
<td>14.0</td>
<td>15.0</td>
<td>13.0</td>
</tr>
<tr>
<td>5 After mechanical filter</td>
<td>6.3</td>
<td>68.0</td>
<td>6.7</td>
<td>3.22</td>
<td>0.60</td>
<td>209.0</td>
<td>13.0</td>
<td>9.9</td>
<td>12.2</td>
</tr>
<tr>
<td>6 With denitrification</td>
<td>-</td>
<td>94.0</td>
<td>3.6</td>
<td>0.05</td>
<td>0.18</td>
<td>95.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

We apply the equiprocentration methodology for a joint assessment of three regimes by the sum of purification percentages in three purification regimes: 1 - existing; 2 - with a lighting and aeration installation; 2a - with a lighting and aeration installation + strainer; 3- with denitrification.

Table 4. Efficiency of recycled water treatment in industrial conditions for the main elements harmful to fish (%).

<table>
<thead>
<tr>
<th>Source</th>
<th>COD. mgO₂/l</th>
<th>% (% COD)</th>
<th>NO₂⁻. mg/l</th>
<th>% (% NO₂⁻)</th>
<th>BOD. mgO₂/l</th>
<th>% (% BOD)</th>
<th>SS. mg/l</th>
<th>% (% SS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 At the exit from the pool</td>
<td>860.0</td>
<td>-</td>
<td>158.0</td>
<td>-</td>
<td>80.0</td>
<td>-</td>
<td>99.5</td>
<td>-</td>
</tr>
<tr>
<td>2 After biofilter</td>
<td>430.0</td>
<td>50</td>
<td>142.0</td>
<td>10.1</td>
<td>76.0</td>
<td>5</td>
<td>58.5</td>
<td>41.2</td>
</tr>
</tbody>
</table>
With aeration and lighting installation (after 10 days) From the pools 530.0 - 218.0 - 80.0 - 86.3 - 4

After biofilter 88.0 83.4 189.0 13.3 15.0 81.5 13.0 84.9

After mechanical filter 68.0 81.2 209.0 4.1 9.9 87.6 12.2 85.9

With denitrification 94.0 82.2 95.0 56.4 12.6 84.5 36.4 61.2

The sum of percent of the cleaning efficiency by the modes is: 1 - 126.5; 2 - 263.1; 2a - 258.8; 3 - 284.3. You can see that the best mode is water treatment with denitrification, in second place is the regime with a lighting and aeration installation.

Regarding the adsorption properties of rice straw, the results of studies of four variants of water purification technology in a laboratory installation using Betamesh 75 mesh, rice straw as a filtrant and as an sorbent are presented in Table 5.

Table 5. The results of the analysis of recycled water after treatment.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>After cleaning according to the scheme 1</th>
<th>After cleaning according to the scheme 2</th>
<th>After cleaning according to the scheme 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.7±0.2</td>
<td>7.2 ± 0.2</td>
<td>7.1± 0.2</td>
</tr>
<tr>
<td>Suspended substances, mg/l</td>
<td>&lt; 3</td>
<td>3.2 ± 1.0</td>
<td>53.5 ± 5.4</td>
</tr>
<tr>
<td>COD, mg/l</td>
<td>45±9</td>
<td>44 ± 9</td>
<td>125± 19</td>
</tr>
<tr>
<td>BOD, mgO₂/l</td>
<td>12±2</td>
<td>8.6 ± 1.2</td>
<td>29 ± 4</td>
</tr>
<tr>
<td>O₂, mg/l</td>
<td>8.5±0.3</td>
<td>8.6 ± 0.3</td>
<td>7.7 ± 0.2</td>
</tr>
<tr>
<td>NH₄, mg/l</td>
<td>0.34±.12</td>
<td>0.42 ±0.15</td>
<td>0.53± 0.19</td>
</tr>
<tr>
<td>NO₂, mg/l</td>
<td>1.2±0.2</td>
<td>1.2 ± 0.2</td>
<td>1.2 ± 0.2</td>
</tr>
<tr>
<td>NO₃, mg/l</td>
<td>156±36</td>
<td>158 ±36</td>
<td>118 ± 27</td>
</tr>
<tr>
<td>PO₄, mg/l</td>
<td>8.8±1.1</td>
<td>8.8±1.1</td>
<td>8.7±1.1</td>
</tr>
</tbody>
</table>

As a result of pilot tests, it was revealed that for the removal of suspended solids, COD and BOD, Scheme 4 turned out to be the most effective, providing for filtering through rice straw activated by NaOH and KOH with subsequent carbonization.
4 Discussion

An indirect indicator of the effectiveness of water purification with a lighting and aeration installation is an increase over 2 months of pilot - industrial operation of the weight growth of fish growing by 20-30% per month with more complete use of feed due to increased transparency of water.

Thus, for existing and newly designed fish breeding plants, it is recommended to integrate a lighting and aeration unit and / or denitrification unit into them.

Lighting and aeration installation is easy to operate, in case of lack of power it is possible to install additional similar modules, as well as in case of leakage, safety is ensured - the voltage supplied to the LEDs is no more than 12V.

It should be noted that samples of treated wastewater were taken from the zone of biomass carriers. According to a visual inspection of the analyzes, an active process of the development of microorganisms was observed at the bottom of the biofilter. A less intensive growth proceeded in the corners of the biofilter body due to the low mobility of the medium being cleaned in these zones. Thus, given the fact that the lighting and aeration installation, operating at full capacity, allowed to achieve a 90% increase in COD and 81% in BOD, and the illumination of the most distant bottom areas was at least 500 Lux, the ALE power fully corresponded to the biofilter needs for lighting. And due to deeper water treatment using an aeration and lighting installation, the increase in fish mass in the pools increased by 20 - 25%, which is an economic incentive for the industrial use of the new technology.

An experiment using the original rice straw and activated in various ways significantly reduced the COD, BOD, and suspended solids, but ammonium nitrogen concentrations did not reach satisfactory values. In all likelihood, this was due to the high content of organic substances in the treated water, which allowed them to "win" in the competitive adsorption on the surface of the sorbent from rice straw.

5 Conclusions

Based on the results and studies, it can be concluded that the efficiency of biological treatment at fish-breeding enterprises is improved by integrating the lighting and aeration unit into the biofilter, thereby reducing the cost of denitrification or abandoning it. The light spectrum for illumination of the biocenosis of the biofilter is accepted blue-red, and also to ensure the safe operation of the lighting and aeration installation - the voltage supplied to the LEDs should be no more than 12V.

During the experiment with rice straw, it was found that if there are high values of COD and BOD in water treatment plants for fish farms, it is necessary to provide for biological water or physical water treatment before sorption treatment.

References


