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ORIGINAL PAPER

Results regarding the control of the dissolved oxygen concentration in wastewater treatment processes

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Abstract

The paper deals with a comparative analysis of the dissolved oxygen concentration control in the case of two types of wastewater treatment reactors: activated sludge reactor and aerobic biofilm reactor. The analysis took place using two pilot plants that exist within "Dunărea de Jos" University of Galaţi: a plant for treating wastewaters from food industry using activated sludge and a biofilter of trickling type included in a recirculating aquaculture system. In the case of the first plant experimental results that prove the possibility of the direct control of the dissolved oxygen concentration in the aerobic bioreactor are presented while in the case of the second plant it is shown that this control strategy does not offer the desired results. For this plant a modified strategy of the dissolved oxygen concentration in the trickling biofilter through the variation of dissolved oxygen level in the aquaculture tanks is proposed. In both cases experimental results that prove the influence of dissolved oxygen level on the efficiency of the wastewater treatment technologies are also presented.

Keywords: Wastewater treatment process, Activated sludge reactor, Trickling biofilter, Dissolved oxygen control, Recirculating aquaculture system.

Introduction

The wastewater treatment became more than a necessity, a responsibility, and every producer must improve the treatment processes [1]. [2]. Various types of treatment were developed during the past years and this domain has almost no technological secrets, but the big challenge is the process control. One of the main problems in adopting control solutions in the case of wastewater treatment processes with activated sludge is the lack or the high cost of measuring instruments for the main variables of the bioprocesses (biomass concentration, COD concentration etc.).

Whatever the used technology, a crucial issue in the case of aerobic wastewater treatment processes is to control the dissolved oxygen concentration. Ensuring a satisfactory level of dissolved oxygen allows the normal development of the microbial wastewater treatment processes. As there are several methods of biological wastewater treatment (biological treatment processes with biofilm, with biomass in suspension etc.), it is very important to establish how to achieve the dissolved oxygen concentration control, so that the process efficiency to be the highest. In the case of the activated sludge reactor there are many approaches in the literature regarding the dissolved oxygen control: PI and PID-control, fuzzy logic, nonlinear control, model based control etc. [3], [4], [5]. Unfortunately, most published studies have been performed in numerical simulation regime. In the case of the used of trickling biofilters the control issue is very difficult, because the basic nitrification processes occur at a biofilm scale, the model of this filter being given by a set of partial derivatives equations with respect to two spatial coordinates [6], [7]. This is the reason that the design of a control structure for the dissolved oxygen concentration in a trickling biofilter requires the

knowledge of the dynamic properties of the nitrification process that takes place in biofilter. The cited literature concerning the dynamic properties of the trickling filter is not able to provide significant information, suitable for this task.

This paper presents the results obtained for the control problem of dissolved oxygen concentration in the two types of wastewater treatment processes. The purpose of the paper is the validation of the control strategies, but also highlighting the problems which may occur in the implementation of the control solutions.

Materials and methods

The study of the control oxygen concentration has been made using two wastewater treatment plants that exist within "Dunărea de Jos" University of Galaţi. The first plant processes wastewaters from food industry. It uses the principle of biological treatment in aerobic conditions with activated sludge. The objective of this pilot plant, which is completely controlled by the computer (Figure 1), was the efficiency improvement of the biological treatment processes of various types of wastewaters from food industry in aerobic conditions, using different control methods. This concept leads to a flexible design which allows us to interchange easily the treatment profiles [3].

Figure 1. Wastewater treatment pilot plant

The treatment plant consists in the following components:

- the feeding tank has the capacity of 100 L and the ability to maintain the wastewater inside at almost constant characteristics due to its refrigeration equipment (1 – 6^{O}C). The feeding flow can be controlled through a peristaltic pump with a 12 l/h maximum flow. Before being pumped into the tanks the wastewater can be heated in a small expansion tank;

- the aeration tank is the heart of the biological treatment process. Here the wastewater is mixed with the activated sludge and to fulfill the process it is also mixed with air. The air is bubbled into the aeration tank through a set of air ejectors which have also a mixing role. To be able to control the medium homogeneity, the aeration tank is also equipped with a mechanical paddle mixer with three rotation speeds: 60rpm, 180rpm and 300rpm. The aeration tank working volume is 35L. The treatment temperature can be online monitored through a temperature transducer and controlled through an electric heating resistance both mounted inside the tank. The pH can also be online monitored through a pH electrode and controlled using two peristaltic pumps, one for acid and the other for base (acid and base tanks). The turbidity can be online monitored with a dedicated optical electrode. The

evolution of the biomass can be indirectly estimated through the turbidity values; the correlation between the two variables is usually made offline by measuring the sludge dry matter. The aeration tank is also provided with an ORP (oxide-reduction potential) transducer which is able to monitor the process under a concentration of 0 mg/L dissolved oxygen. The ORP potential can be correlated, in some cases, with the COD of the wastewater;

- the sludge flocks formed in the aeration tank are allowed to settle in the clarifier. This tank is provided with an ultrasonic level transducer which gives the flexibility to work at different retention times according to the chosen treatment scheme. From the bottom of the clarifier the settled sludge is recycled with a peristaltic pump back into the aeration tank.

- the transducer signals are captured by a PCI data acquisition board. A HMI (*Human-Machine Interface*) facilitates the process control and monitoring (Figure 2). The data can be stored and processed thereafter.

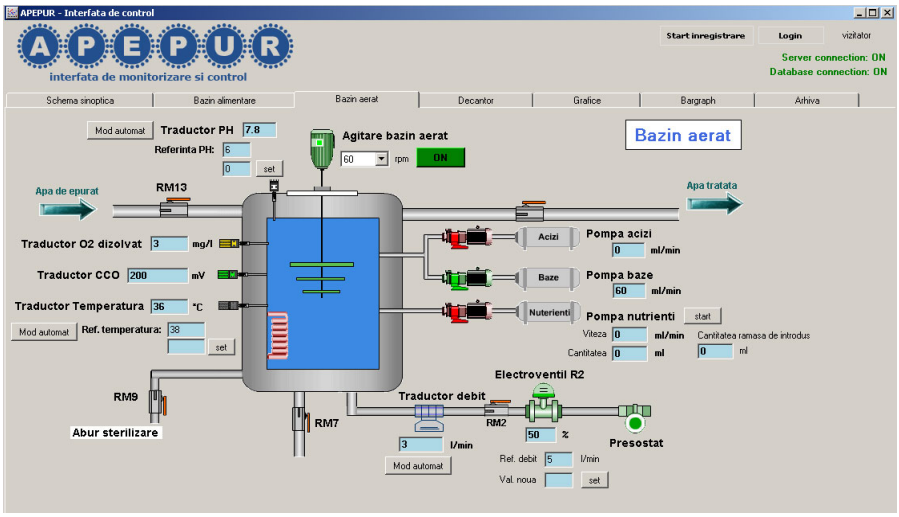

Figure 2. Main window of the HMI

One of the most important variables in an aerobic treatment process is the DO (dissolved oxygen concentration) which is controlled by a cascade control structure. The cascade control system contains an inner loop (air flow control loop) that has a fast dynamics and an outer loop (the DO control loop) that has slower dynamics. The air flow is on-line measured with a flow meter and it is controlled with an electric continuous valve. The DO concentration is on-line measured with an electrochemical electrode mounted in the aeration tank and it is controlled using the aeration rate as a control variable.

A PI controller was implemented to control the dissolved oxygen concentration in the aerated tank. Since the control variable is limited to a higher value given by the air generator used to provide the aeration - in the case of this pilot plant: 25 l/min - and the controller includes an integral component, it was necessary to introduce an anti-windup structure. This structure prevents the achievement of some unacceptable values for the integral component, when the control variable is saturated.

The second wastewater treatment equipment is the one from a pilot plant for fish intensive growth in recirculating regime (Figure 3). The pilot plant consists in two components: the first component is for the development of various fish species, starting with the less demanding species (e.g. carp), through "difficult" species as trout, sturgeons (beluga, sevruga etc.), and the second component is for the wastewater treatment so that to ensure optimal conditions for the development of the fish species in the recirculating system [8].

The system contains four octagonal tanks with 1 m^3 capacity each, in which the intensive growth of the fish takes place. The tank aeration is done in the following way:

through the ejection effect the air from the atmosphere in the influx is transferred with special valves which bring water into the tanks. The wastewater from the four aquaculture tanks is collected through natural flow in the mechanical treatment system (Drum filter). Here the separation and storage of the solids substances are achieved. Together with the solids removal, a part of the water is also removed, this being used to clean the filter. The compensation of this quantity of water is achieved by approximation and it is done manually from the public water network. In the next phase the water flows into a tank with a buffer accumulator role. From this tank, the water is transferred using a pump to two filters (with sand and coal respectively) and it is brought to the top of the biological filter of trickling type. The trickling biofilter performs, under aerobic conditions, the transformation of the ammonium in nitrites and then in nitrates. Collecting water at atmospheric pressure is done in the tank below the biofilter. From this point, the water is circulated, using the pump P_2, through the chemical filter (for denitrification) and UV filter, being transferred under pressure in the aquaculture tanks. A constant level of the water is maintained in these tanks through an overflow system. The recirculating intensive aquaculture plant is equipped with a monitoring and control system that contains an HMI presented in Figure 4. For the dissolved oxygen concentration control an ON/OFF controller is used. The information regarding the dissolved oxygen concentration is given by a dissolved oxygen transducer that is located in the tank below the biofilter. The aeration is made using an air generator if the aeration valve is ON.

Figure 3. The recirculating aquaculture system

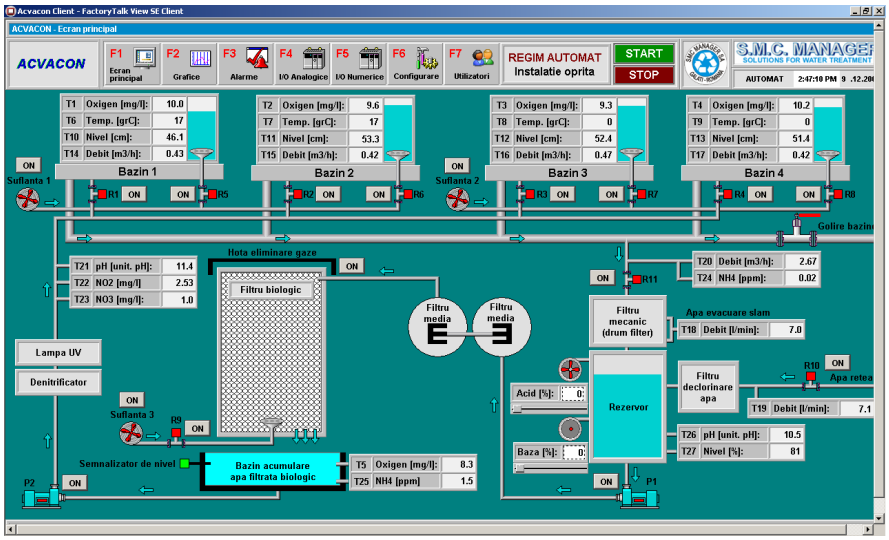

Figure 4. The general synoptic scheme of the human-machine interface.

Results and Discussion

Results regarding the dissolved oxygen control for an activated sludge reactor

For the validation of the dissolved oxygen control in the aerated tank two experiments were made using wastewater from the dairy industry. The wastewater used in the two experiments was collected at different time moments, so the initial concentration of organic substances will be different from one experiment to the other. In the first experiment the following values of the main variables were imposed: the initial concentration of organic substances = 1990 mgCOD/l, the wastewater inflow = 3l/h and the dissolved oxygen concentration setpoint was 2 mg/l. Figure 5 presents the results obtained in the experiment. In this figure one can notice a good behaviour of the designed controller. At the beginning of the experiment the microorganisms activity is reduced which justifies the big response time (approx. 100 min). Figure 6 presents the graphic evolution of the control variable – the aeration rate, and Figure 7 presents the wastewater turbidity expressed in NTU units which is correlated to the biomass from the aerated tank. Analyzing Figures 6 and 7 one can notice a good correlation between the aeration rate and the total solids in suspension. So if the microorganisms population develops well it can be noticed that the aeration rate increases, that is necessary for the dissolved oxygen concentration to remain to the imposed setpoint. In the same experiment wastewater samples at regular intervals for off-line analysis of the load with organic substrate were taken. Data are presented in Table 1 and they show a good evolution of the organic substrate concentration in wastewater, in ensuring a satisfactory dissolved oxygen concentration.

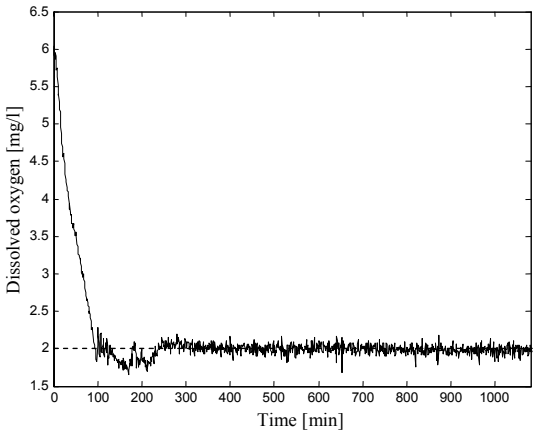

Figure 5. Evolution of the dissolved oxygen concentration: solid line continua – pilot plant, dotted line – setpoint

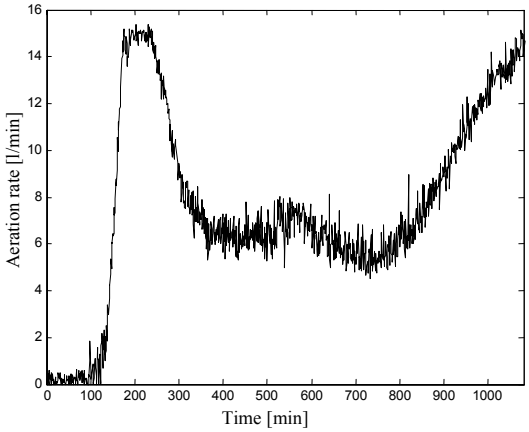

Figure 6. Evolution of the control variable

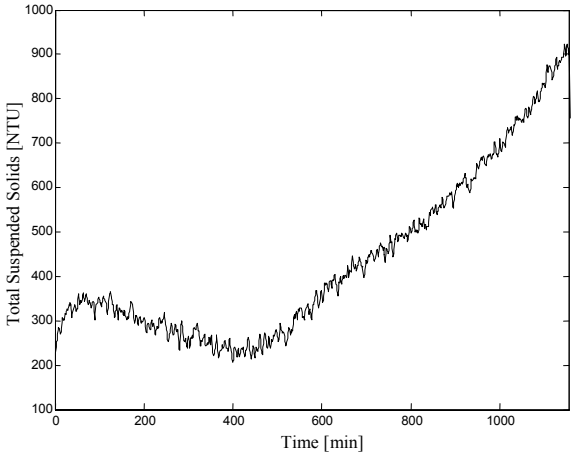

Figure 7. Evolution of the total solids in suspension

Table 1. Organic substrate evolution

Sample	Organic substrate [mgCOD/l]
1	1990
2	1754
3	1354
4	986
5	832

In the second experiment a bigger load of organic substances (2409 mgCOD/l) was considered. The supplying flow with wastewater was equal to 3 l/h, and the dissolved oxygen concentration setpoint was modified between the values 2 mg/l and 2.5 mg/l. The obtained result is presented in Figure 8 and Figure 9 shows the control variables. Analyzing Figures 8 and 9 it can be noticed a good behavior of the control structure until the moment 875 min. At this moment the dissolved oxygen concentration decreases under the setpoint value due to the high values of consumption of dissolved oxygen and biomass concentration, as it can be seen in Figure 10. As a result, the control variable reaches the maximum admissible value entering in saturation regime. This causes a decrease of the dissolved oxygen value under the imposed setpoint, showing that the adopted load for this experiment exceeds the limits to which the pilot plant was designed.

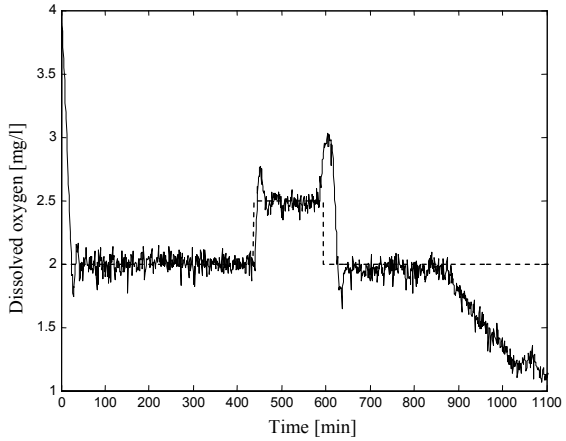

Figure 8. Evolution of the dissolved oxygen concentration: solid line continua – pilot plant, dotted line – setpoint

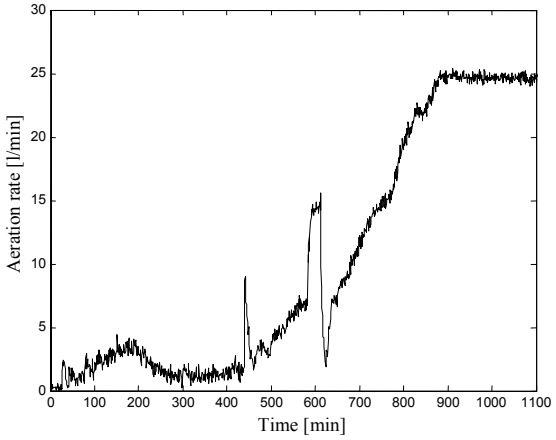

Figure 9. Evolution of the control variable

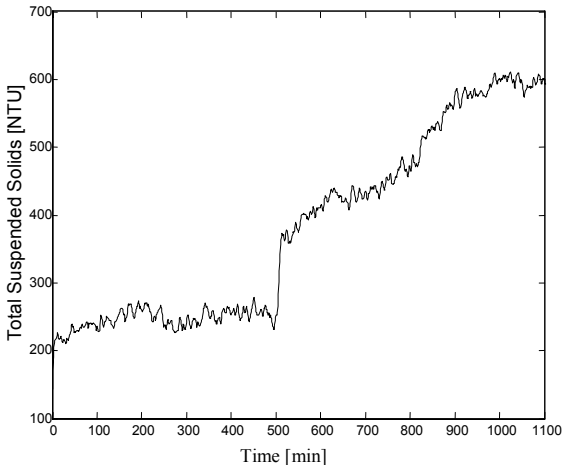

Figure 10. Evolution of the total solids in suspension

Results regarding the dissolved oxygen control for an aerobic biofilm reactor

For validating the direct control structure of the dissolved oxygen concentration in the biofilter through the air generators located below the trickling balls, the following experiment was achieved: at different moments of time the valve that allows the air access from the air generator to the air blowers was switched in ON and OFF positions. The obtained experimental results were presented in Figure 11 and they show that the dissolved oxygen concentration from the wastewater that go through the trickling biofilter is influenced especially by the dissolved oxygen concentration from the aquaculture tanks. As a consequence, the aeration effect in the biofilter cannot be clearly revealed. The explanation results from the biofilter particularities used in the aquaculture system: in the case of the trickling biofilter of small height there is an important contribution of oxygen, due to the space that exists between the balls even if the aeration control is null. Since there is an intrinsic aeration, the aeration rate can be omitted as a biofilter control variable. Thus from the date analysis, it results that the dissolved oxygen concentration at the biofilter output can be controlled through the dissolved oxygen concentration from the aquaculture tanks [8]. The oxygen concentrations in these tanks can be modified between certain limits, which are specific to the fish species that are growing in the aquaculture system. By changing the setpoints of the oxygen concentration control loops, the oxygen concentration at the biofilter output can be also controlled.

The dissolved oxygen concentration at the biofilter input affects significantly the nitrification process. This statement is illustrated by the experimental recording shown in

Figure 12, where the evolutions of the following variables are given: the oxygen concentration at the biofilter output (O_2BF), the ammonium concentration at the aquaculture tanks output (NH_4C) and the concentrations of ammonium at the biofilter output (NH_4FB). It can be noticed that the ammonium concentration at the trickling biofilter output depends very much of the oxygen concentration at the biofilter output. Thus, in terms of an almost constant ammonium concentration at the four aquaculture tank outputs, the modifications of the ammonium concentration at the biofilter output are determined by the oxygen concentration at the biofilter output.

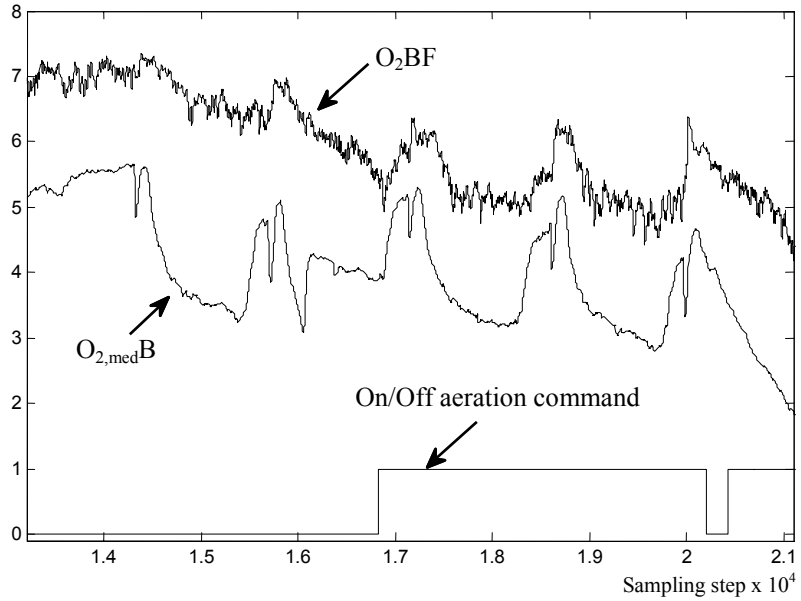

Figure 11. The relationship between the average of the oxygen concentrations in the tanks ($O_{2,med}$B [mg/l]), oxygen concentrations at the biofilter output (O_2BF [mg/l]) and the On/Off aeration command

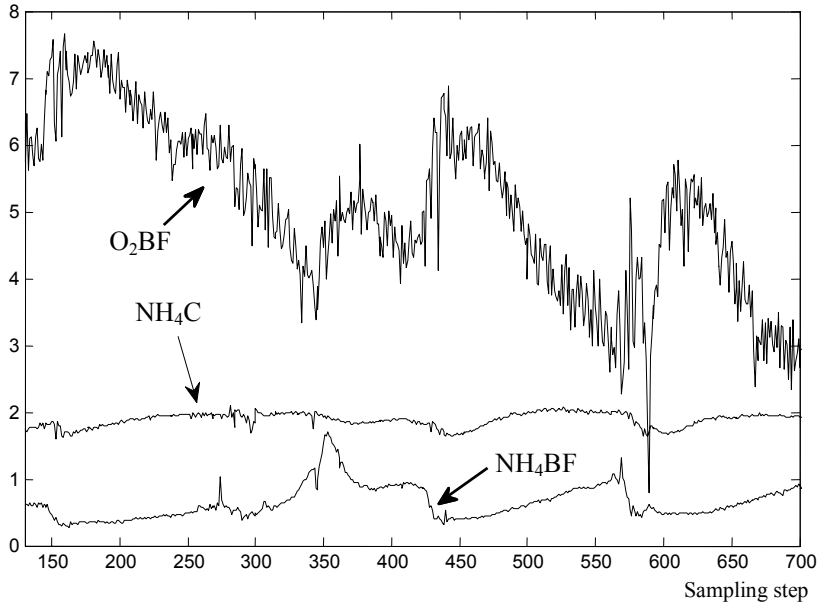

Figure 12. The relationship between, the ammonium concentration to the aquaculture tank output (NH_4C[mg/l]), the ammonium and oxygen concentrations at the biofilter output (NH_4BF [mg/l] and O_2BF respectively [mg/l])

Conclusions

The obtained experimental results led to the following conclusions:

1. The dissolved oxygen concentration control for an activated sludge bioreactor can be easily achieved with very good results if the limits of the organic substrate load for that the pilot plant was designed are respected. The reaching of a correct dissolved oxygen level in the aerated bioreactor allows the ensuring of the optimal conditions for microorganisms growth and, as a consequence, for the wastewater treatment;
2. It was experimentally found that the effect of biofilter aeration on the oxygen concentration to its output is very low and therefore it does not justify the providing of an aerating system aiming to control the nitrification process to a biofilter of trickling type;
3. It was also experimentally found that the effect of the aquaculture tank aeration on the oxygen concentration at the biofilter output is significant. It was established that when needed, the oxygen setpoint in the aquaculture tanks can be used as a control variable for the oxygen concentration at the biofilter output. In the same time it influences the nitrification processes that take place at the biofilter level.

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