ABSTRACT

of PhD thesis

„WASTEWATER TREATMENT USING AEROBIC GRANULAR SLUDGE”

Key words: aerobic granular sludge, SBR, wastewater treatment performances.

Biological wastewater treatment recent extensive research have shown that fixed biomass systems are typically more efficient than suspended biomass systems.

The granulation process of aerobic activated sludge and its use in various wastewater treatment systems is a current biotechnological concern, as these systems are superior to conventional wastewater treatment plants.

The novelty of this thesis is represented by the fact that there are no nationally known wastewater treatment applications of aerobic granular sludge in sequencing batch reactor, even less in a continuous system.

The present paper had the following goals: ◆ obtaining aerobic granular sludge in a Sequencing Batch Reactor (SBR) using a synthetic culture medium; ◆ adapting the system in order to obtain aerobic granular sludge using high organic industrial wastewater; ◆ assessment of aerobic granular sludge biocenosis diversity; ◆ assessment of high organic industrial wastewater treatment performances using aerobic granular sludge; ◆ assessment of biotoxic wastewater treatment performances using aerobic granular sludge; ◆ optimization of continous flow bioreactor and wastewater treatment performances using aerobic granular sludge.

Thus, the thesis was divided into two parts: ***Bibliographical study*** and ***Personal research***.

In the first part of the thesis – ***Bibliographic study*** –the most important data concerning aerobic granular sludge formation and the feasibility for its wastewater treatment technological application are presented.

The second part of this thesis – ***Personal research*** –presents the materials and methods used, the results and discussions, as well as general conclusions.

In the chapter ***"Experimental conditions. Materials and methods"*** the bioreactors used in order to obtain aerobic granular sludge and the determination methods are presented: **pH** was measured with a Consort multiparameter; **dissolved oxygen concentration** in the bioreactor was measured with WTW Oxi320 oxygen meter; **organic matter content** was rated as chemical oxygen demand (COD, mg O_2/L) according to the ISO standard (SR ISO 6060:1996) and as biochemical oxygen demand (BOD, mg O_2/L) according to the SR EN 1899/1.3; 2-02; main macronutrient concentration NH_4^+, NO_2^- and NO_3^- were determined according to the SR EN ISO 14911:2003 and SR EN ISO 10304/1:2009 standards (for the last two indicators), respectively, using ion chromatography system ICS-3000 (Dionex, USA); phosphorus was determined spectrophotometrically according to SR EN 6878:2005; granules formation and biocenosis dynamic were monitored by microscopic investigation (trinocular B1, Optech microscope).

The bioreactor used in order to obtain aerobic granular sludge consisted of a cylinder with a height of 100 cm and a diameter of 10 cm, resulting in a height/diameter ratio of 10, and having a useful capacity of 7 liters. The cyclic operation of the SBR systems was ensured by a Programable Logic Controller (PLC) which controlled the feeding pumps and air inlet and effluent outlet electrovalves.

To obtain aerobic granular sludge a synthetic culture medium was used. Then, the experiments focused on obtaining aerobic granular sludge using industrial wastewater characterized by high organic load.

The **new** aerobic granular sludge continuous flow **bioreactor** consisted of: influential vessel (60 L); aerobic bioreactor rectangular, with a volume of 10 liters, fitted with blades to protect agains turmoils created by aeration; granule settling and recirculation area; secondary clarifier; spillway; effluent collection vessel (60 L). This new bioreactor represents a national novelty.

In the Chapter ***"Results and discussions concerning high organic wastewater treatment using aerobic granular sludge systems"*** the experiments conducted in order to achieve the above proposed goals are presented.

The possibility of obtaining aerobic granular sludge was tested in SBR by using a synthetic growth medium. The inoculum consisted of 5 g/L conventional activated sludge, sampled from a municipal wastewater treatment plant. Experiments showed the feasibility of aerobic granular sludge formation after 100 days of operation. At the end of the experiment, the granules had diameters between 1 and 4 mm.

The results enabled further experiments in order to obtain aerobic granular sludge using industrial high organic wastewater.

The inoculum used was represented by well floculated conventional activated sludge (5 g/L), sampled from Focşani wastewater treatment plant.

The dairy wastewater used as influent was characterized by high organic load and relatively high concentrations of ammonium, total nitrogen and total phosphorus, which exceeded the limits imposed by national legislation regarding discharge into municipal sewerage system (NTPA 002/2002).

The obtained aerobic granular sludge showed adaptability and stability, taking in consideration the high concentrations of organic load and nutrients (COD: 1689 - 4610 mg O_2/l, BOD5: 492 - 1806 mg O_2/L, NH_4^+: 23-114 mg/L; Ntot: 53 - 162 mg/L, Ptot: 10.4 - 50 mg/L). The recorded treatment performances were up to 96% for the COD, 97% for BOD5, almost 100% of NH_4^+ and 72% for Ntot and Ptot, the effluent being withing the imposed limits by the national legislation (NTPA 002).

The biocenosis diversity of the aerobic granular sludge was represented, in a first phase, by the domniance of small ciliates. Along with sludge maturation, the number of filamentous bacteria decreased, and the occurrence of species *Vorticella sp.* in the system were noted.

The experiments continued by testing the high organic wastewater performances depending on the type of inoculum used. For these experiments, three SBR bioreactors were used: G-SBR was inoculated with aerobic granular sludge having a diameter between 4 and 6 mm, obtained in the previous phase; GM-SBR was inoculated with crushed aerobic granular sludge with a diameter less than 1 mm, obtained in the previous phase; D-SBR was inoculated with conventional active sludge sampled from a municipal wastewater treatment plant.

The influent wastewater was collected from a local milk-processing factory and was characterised by high organic load and nutrients concentrations: COD: 1723 – 3550 mg O_2/L; BOD_5: 492 – 1806 mgO_2/L; NH_4^+: 64,6- 114 mg/L; Ntot: 64 – 162 mg/L; Ptot: 5,04 – 21,5 mg/L.

It was observed that the granule size, by the specific contact surface/nutrient diffusion area, represents an essential factor that can influence the wastewater treatment performances, being closely related to the size of the anoxic area and thus directly proportional to the intensity of anoxic/anaerobic processes in SBR systems.

All three systems showed good treatment performances. The COD removal was 93% for G-SBR, 91% for D-SBR, and 97% GM-SBR.

Better nutrient removal performance were obtained in GM-SBR, where granules ranged in size from 500 to 1600 µm, being up to 60% for NO_2^- and more than 90% the NO_3^-.

The biocenosis dynamics was characterized by the appearance of rotifers, solitary stalk ciliated (*Vorticella microstoma*, *V. Convalaria*), *Cyclopyxis sp.* species and testaceous amoebae.

In order to assess the treatment of biotoxic wastewater using aerobic granular sludge, the SBR was inoculated with aerobic granular sludge with a diameter between 0.5 and 1.8 mm, obtained from previous experiments.

The bioreactors were fed with 50% dairy wastewater in order to provide the needed biodegradable substrate, necessary macro and trace elements, and 50% phenol-rich water. The phenol concentration in the influent was approx. 1 g/L.

Algorithm 1 led to production of nitrite and its oxidation to nitrate inhibiton. Gradually, the system changed its behavior, adapting to the oxidation of nitrite to nitrate and simultaneous denitrification - specific behavior of aerobic granular sludge. Thereby total phenol consumption was achieved, 2.8 kg/m^3/day of phenol being successfully removed in stable conditions, while maintaining aerobic granular sludge quality and performance and compliance with the maximum national limits imposed for discharging in surface waters (NTPA 001).

Since aerobic granular sludge adapted after a long time to the nitrification-denitrification processes, and the inhibitory effect of phenol interfered with denitrification in the first 64 cycles, the use of a repetitive cycle of continuous filling, anoxic reaction, aerobic reaction was proposed (Algorithm 2).

This algorithm enabled nitrification-denitrification processes without any adjustment period required for the aerobic granular sludge, as a result of lower toxic/inhibitor consequences.

The optimisation of reactor design and conditions for aerobic granules to perform under continuous flow operation led to the making of a bioreactor with two serial settlers, one for high settling speed biomass separation and the second for biomass suspension removal. The inoculum used was represented by aerobic granular sludge with a diameter of 30 - 550μm.

The influent was characterized by: COD: 1523 - 2850 mg O_2/L; BOD5: 427-1313 mg O_2/L; NH_4^+: 24.6- 84 mg/L; Ntot: 34 - 136 mg/L; Ptot: 3.12 - 18.7 mg/L.

Granular structural destabilization reflected on the continuous system that functioned with lower performances by approx. 25% for COD and BOD5, 36% for NH_4^+, 80% for Ntot. and 95% Ptot when compared to SBR.

Granular size decrease had negative impact on the biocenosis diversity, pointing out the absence of solitary stalk ciliated and fewer rotifers.

The new optimized continuous flow bioreactor showed good treatment performances, the experimental results on residual organic concentrations and nutrient load being below limits imposed by national legislation regarding discharge into municipal sewerage system.

The reactor was inoculated with aerobic granular sludge of sizes between 100 and 3000 μm, previously obtained in SBR treating the same influent – dairy industry wastewater. 2 g d.s./L were used as inoculum.

To assess the effectiveness of the new bioreactor, the dairy industry wastewater used as influent had the following physicochemical characteristics: COD: 1296 - 2728 mg O_2/L; CBO5: 481-813 mg O_2/L; NH_4^+: 28 - 44 mg/L; PO_4^{3-}: 11.2 - 28.3 mg/L; Ntot: 39.3 - 76.2 mg/L; Ptot: 2.8 - 6.2 mg/L; pH: 6.59 - 7.18.

Good treatment performances were registered, the effluent being within the limits imposed by national legislation regarding discharge into municipal sewerage system (NTPA 002), as well as the imposed limits for discharging in surface waters (NTPA 001).

The remaining organic load concentrations, expressed as COD varied from 250 to 101 mg O2/L, but 50% of cases, it exceeded the maximum imposed limits for discharging in surface waters (NTPA 001).

The ammonium concentration in the effluent was within the limits for discharge into municipal sewerage system (NTPA 002) and, in most cases, within the limits for discharge in surface waters (NTPA 001), the remaining concentrations varying depending on the influent quality.

Nitrate concentration in the effluent plant was within the limits required for surface waters discharge, not exceeding 5 mg/L, indicating simultaneous nitrification and denitrification processes, a definitory characteristic of aerobic granular sludge.

Chapter IV presents the main conslusions resulted from the experiments.