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Effect of sequencing batch cycle strategy on the treatment of a simulated textile wastewater with aerobic granular sludge

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ABSTRACT

Aerobic granular sludge was successfully developed on a simulated textile effluent with an added azo dye, on a non-tubular sequential batch reactor (SBR), with better granulation results than in a dye-free control SBR fed with the same base medium. The overall performance of the treatment was very good, with high color and chemical oxygen demand (COD) removal yields (up to 85% and 80%, respectively). Operation under two sequencing batch cycle strategies, i.e., with a single anaerobic/aerobic reaction phase or under intermittent aeration, showed that the latter generally improved the treatment performance. Under intermittent aeration, biomass accumulation was induced, with faster settling aggregates, leading to a higher COD removal yield. Although a lower decolorization rate was observed in the first 30 min of anaerobic reaction, as compared to the single phase strategy, the overall color removal remained high. This work demonstrates the applicability of the new aerobic granular sludge technology for the treatment of textile effluents.

1. Introduction

The modern textile industry has been swift to respond to the increased demand for textile products worldwide, and its wastewater load has been increasing proportionally [1]. This situation has sometimes led to the degradation of the quality of receiving water bodies, limiting their use for several purposes [2]. This industrial sector generates large quantities of wastewater, e.g., in Europe, a water consumption of 50–240 m^3 per ton of textile product has been estimated [3]. These effluents are usually heavily loaded with organic carbon and color compounds, the latter being azo dyes in an estimated 70% of the cases [4]. The treatment of textile effluents poses a major challenge in environmental protection, namely in what regards cost and quality of the final effluent. Physicochemical treatments are available but costly, and in spite of notable achievements lately reported on the application of bio-treatments to textile wastewaters [1], the latter are not yet efficient enough notably in what regards the elimination of synthetic colorants.

Biological systems combining anaerobic and aerobic phases have been proposed for the treatment of textile effluents, with dye reduction occurring in the anaerobic phase, resulting in decolorization, and further organic load removal being obtained in the subsequent aerobic phase, with possible oxidation of dye reduction metabolites [5–7]. Sequential batch reactors (SBR) have been often reported as good options for this purpose [5,7] due to their operational flexibility and simplicity, and compact layout [5]. The SBR configuration in activated sludge treatment systems is characterized by cyclic, fill-an-draw operation of a single tank, dispensing the use of dedicated settlers. The standard cycle comprises five steps: fill (influent feed, static or with agitation and/or aeration), react (with agitation and/or aeration), settle (sedimentation of the biomass/clarification of the treated liquor), draw (clarified effluent discharge) and idle [8]. Excess biomass can be withdrawn during the react or draw phases. This system allows the manipulation of reaction and settling times in each cycle, in response to variations

Abbreviations: 2A1N4S, 2-amino-1-naphthol-4-sulphonate; 4A1NS, 4-amino-1-naphthalene sulphonate; AR14, azo dye acid red 14; COD, chemical oxygen demand; $E_{Ag/AgCl}$, oxidation–reduction potential value against the silver/silver chloride standard; H/D, height-to-diameter ratio of the working bioreactor volume; HPLC, high performance liquid chromatography; MLVSS, mixed liquor volatile suspended solids; ORP, oxidation-reduction potential; OUR, oxygen uptake rate; RSD, relative standard deviation; SBR, sequential batch reactor; SBR1, sequential batch reactor operated without dye; SBR2, sequential batch reactor operated with dye; SOUR, specific oxygen uptake rate; SVI, sludge volume index, measured after a 5-min (SVI_5) and a 30-min (SVI_{30}) settling time; TSS, total suspended solids; VSS, volatile suspended solids.

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in input organic loads and biomass settleability. This feature is particularly useful for wastewaters coming from batchwise industrial processes, such as textile dyeing, which often exhibit wide variations in flow rate and composition [5,6]. SBR operation also easily allows the implementation of the two-step anaerobic-aerobic reaction sequence required for reductive decolorization and organic load oxidation in dye-containing textile wastewaters [6,7].

Aerobic granular sludge is a new and promising technology for the treatment of industrial wastewaters [9]. Aerobic granules are self-aggregated microorganism clusters with outstanding settling properties, when compared with conventional activated sludge flocs. In the present state-of-the-art they are obtained and maintained only in SBR [10,11] reducing to a few minutes the settling time in these single-tank systems [12]. Very high biomass concentrations can be achieved in the bioreactor, resulting in high organic load treatment capacities and very compact systems [12]. Aerobic and anoxic/anaerobic zones can coexist inside the same granule, in response to the adjustment of aerated and non-aerated periods in the SBR cycle. This provides a unique system for the removal of organic load and nutrients since the major biological reactions can occur simultaneously even throughout the aerated phase, namely, the accumulation of polyphosphates and nitrification in the outer layers and denitrification in the inner granule [10,13,14]. Other advantages of aerobic granules are their robustness in the presence of toxic compounds [15] and the rapid recovery of biological activity and maintenance of granule integrity even after extended storage periods [16–19]. These are especially important in industrial wastewater treatment systems, since toxic compounds can be present and wastewater production often faces interruptions for several days or weeks, according to the manufacturing schedules. Due to these exceptional characteristics, the application of the aerobic granular sludge technology to the treatment of industrial effluents has recently raised attention among researchers [15,20]. Nevertheless, studies on the application of this technology to the treatment of textile wastewaters are still incipient [21].

In most of the reported studies, the tubular configuration has been used in laboratory SBR for aerobic granulation. This configuration is characterized by high height-to-diameter ratios (H/D), in the range of 14–30 [13,22–25], but this geometry is likely to pose implementation difficulties in full-size systems.

In the present study, a non-tubular SBR, with a H/D value of 2.5, was tested. To the authors' best knowledge this is the lowest H/D value reported for aerobic granulation in laboratory conditions, and it was chosen with the purpose of easing a subsequent scale up to industrial system sizes. Thus, in this work, the possibility of aerobic granule development was assessed, using a flocculent activated sludge inoculum fed with a simulated textile wastewater. Treatment performance was evaluated under two cycle strategies, namely, a two-phase anaerobic-aerobic cycle and an intermittent aeration regimen throughout the cycle.

2. Materials and methods

2.1. Simulated textile effluent feed solutions

A carbon source stock solution was prepared with a starch-derived sizing agent used in the textile industry, Emsize E1 (hydroxypropyl-starch, Emsland-Starke GmbH, Germany) as the carbon source. This substrate was pre-hydrolyzed in alkaline conditions (NaOH) as described previously [5], followed by pH adjustment to 7.0 (HCl) and dilution with deionised water to 100 g L^{-1}.

A base feed solution was prepared in deionized water using the carbon source stock solution diluted to a chemical oxygen demand (COD) content of 1000 mg O_2 L^{-1}, and supplemented with pH buffering phosphates and nutrients to the following concentrations: KH_2PO_4 (760 mg L^{-1}), $Na_2HPO_4{\cdot}12H_2O$ (2310 mg L^{-1}), NH_4Cl (140 mg L^{-1}), $MgSO_4{\cdot}7H_2O$ (23 mg L^{-1}), $CaCl_2$ (28 mg L^{-1}), $FeCl_3{\cdot}6H_2O$ (250 μg L^{-1}), $MnSO_4{\cdot}4H_2O$ (40 μg L^{-1}), H_3BO_3 (57 μg L^{-1}), $ZnSO_4{\cdot}7H_2O$ (43 μg L^{-1}), and $(NH_4)_6Mo_7O_{24}{\cdot}4H_2O$ (35 μg L^{-1}). All salts were analytical grade. This solution exhibits a COD:N:P mass ratio of 100:3.7:30. This was the only feed to bioreactor SBR1, which was used as a dye-free control.

An azo dye stock solution was also prepared. The tested azo dye was acid red 14 (AR14, Chromotrope FB, Sigma–Aldrich, 50% dye content), used without further purification. It was dissolved in deionised water to a concentration of 3.0 g L^{-1}.

The synthetic textile effluent (dye-containing) feed was obtained by adding 10 mL of the dye stock solution after 750 mL of the base feed solution, at each cycle, corresponding to an initial, added dye concentration of 20 mg L^{-1} in the bioreactor. The dye stock solution was added from the top directly into bioreactor SBR2, at the end of the fill phase of the operational cycle.

2.2. Non tubular sequencing batch reactor (SBR) configuration

The experiments were conducted in two non tubular SBR, SBR1 and SBR2, each with a working volume of 1.5 L, operated with a volumetric exchange ratio of 50%, the settled effluent being withdrawn at half-height of the reactor's content, and at a hydraulic retention time value of 12 h. Each reactor had a working height of 25 cm and an inner diameter of 10 cm, the height-to-diameter ratio (H/D) value being 2.5. For aeration an air compressor model SPP 15 (Highblow, Japan) was used with a porous membrane diffuser placed at the bottom of each reactor. The air flow rate was approximately 3.0 L min^{-1} for each reactor, giving an aeration rate of 2 v.v.m. The SBR were operated under mechanical stirring during the entire reaction periods, both aerated and non-aerated. The magnetic stirrer used was a bioMIXdrive 1 model with the bioMIX-control MS4 control unit run at 200 r.p.m. (2mag, Germany). The base feed solution was inserted at the bottom of the reactor, at the level of the air diffuser, using a separate peristaltic pump for each reactor (Mini-S 660, Ismatec, Switzerland), and the rapid discharge of the settled supernatant was achieved using a single gear pump for the two reactors (Reglo-Z, Ismatec, Switzerland). A separate peristaltic pump was used to feed the dye stock solution to SBR2. The pumping, aeration and agitation functions were automatically controlled, via an interface, by a dedicated program installed on a personal computer.

2.3. Experimental strategy

The two SBR were operated under the same operational conditions, except for the presence of dye in the feed. In this way, the effect of the dye could be assessed with two independent experiments in all conditions imposed throughout the study. The duration of the operational cycle was kept at 6 h, totaling 4 cycles per day. Each cycle comprised the following phases (Table 1): fill, during which fresh feed was pumped into the reactor, over the settled biomass leftover from the previous cycle, without mechanical mixing; reaction, during which mechanical mixing was applied, both without and with aeration; settling, without mechanical mixing for biomass sedimentation; discharge, during which half of the operational volume was rapidly removed from the clarified supernatant; and idle, a quiescent period to complete the cycle time. Thus, the reactors' liquid volume was renewed twice each day (cycle exchange ratio: 50%). The organic loading rate fed to the reactors was kept at 2.0 kgCOD m^{-3} d^{-1} in all periods.

The experimental strategy included two objectives: (1) following the process of converting the biomass' initial floc morphology to granule morphology (granulation), in the presence and absence