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Reduction of the sludge production in a sequencing batch reactor by addition of chlorine dioxide. Influence on the process performance.

E. Zuriaga-Agustí[1*], G. Garrido-Mauri[1], J.A. Mendoza-Roca[1], A. Bes-Piá[1], J.L. Alonso-Molina[2]

[1] Instituto de Seguridad Industrial, Radiofísica y Medio Ambiente
[2] Instituto Universitario de Ingeniería del Agua y Medio Ambiente
Universitat Politècnica de València. Camino de Vera s/n. 46022 Valencia (Spain)
[*]Corresponding author e-mail: elzuag@etsii.upv.es
Tel.: +34 963877630; fax: +34 963877639.

Abstract

Costs reduction in the activated sludge process in municipal wastewater treatment plants (MWWTPs) has nowadays become of paramount important due to the current economic situation. One of the saving measures that are being currently studied is the reduction of sludge production. In this work, the influence of the addition of chlorine dioxide to a sequencing batch reactor (SBR) on the sludge production and on the process performance has been studied. After preliminary jar-tests to select the ClO_2 concentration range to be studied, two series of experiences were carried out. In the first series of experiments two laboratory SBRs were operated in parallel to test the effect of three different ClO_2 doses. In the second one, three laboratory SBRs were operated in parallel to go on studying the influence of the chlorine dioxide addition on the SBRs performance and to compare two different dosing strategies (directly to the reactor and mixing the oxidant with a part of the sludge in a separated tank). SBRs treated simulated municipal wastewater and they were operated with the same operating strategy. Results showed that doses of 5 and 10 mgClO_2/TSS entailed severe deterioration of the biological process, meanwhile the dose of 2 mgClO_2/gTSS hardly decreased the COD removal performance, implying a reduction of sludge production of 20.2 %. An increase of the dose up to 2.5 mgClO_2/TSS increased the reduction of the sludge production up to 43.4 %, when the oxidant was added directly to the reactor in the anoxic reaction phase.

Keywords: Chlorine dioxide, cell lysis, SBR, sludge reduction

1. Introduction

Reducing sludge production in the activated sludge process implies a diminution of the management costs of the wastewater treatment plants (WWTPs), what is of paramount important in the current economic context.

The mechanisms for sludge reduction techniques are commonly classified into 5 groups: cell lysis plus cryptic growth, uncoupled metabolism, endogenous metabolism, microbial predation and hydrothermal oxidation [1,2]. The enhancement of the endogenous

metabolism in a WWTP is widely used, since it is well known that an increase in the sludge retention time will decrease sludge production.

The application of the other mechanisms is much more limited. In recent years, the sludge reduction by cell lysis and cryptic growth has increased its interest. Cell lysis can be obtained by means of various treatments such as enzymatic hydrolysis, treatment with ultrasound and oxidation.

Focusing on oxidation, some authors have reported about the use of oxidants to enhance the cell lysis. In this way, ozonation has been proposed by several authors [3-5]. The process consists of a sludge ozonation stage and a biodegradation stage, in which a fraction of recycled sludge passes through the ozonation unit (disintegration of suspended solids) and then the lysed sludge is decomposed in the subsequent biological treatment (cryptic growth).

Recent works show promising results. Thus, Hajsardar et al. (2011) reduced the sludge yield (Y) from 0.51 to 0.34 mg biomass/mg COD by adding 30 mgO_3/gTSS [6]. Modeling of the process by extensions of IWA-ASM3 has recently been studied [7].

Jaervik et al. (2011) proposed dosing ozone directly to the aerobic bio-oxidation process to study the effect on the sludge yield. A dose of 39 mgO_3/L·d resulted in a sludge reduction of 50% [8].

Salsabil et al. (2010) reported that sludge reduction with ultrasounds worked slightly better than those obtained by ozone [9]. Zhang et al. (2007) reported sludge reduction between 9.1 to 17.8 % by partial sludge sonication in a Sequencing Batch Reactor (SBR) using a frequency of 25 kHz. The best operating conditions for the sonication were sludge sonication ratio of 3/14, ultrasound intensity of 120 kW/kgDS, and sonication duration of 15 min [10]. However, Mohammadi et al. (2011), working at 20 kHz, warned about the excess of lysis, what could induce effluent deterioration. They established that a maximum 30% of the system sludge could be lysed resulting in approximately 78% reduction of sludge yield [11]. These results coincide with that reported by He et al. (2010) [12].

Due to its low cost and common handling in water and wastewater treatment plants, chlorine has also been studied to enhance lysis and cryptic growth in biomass for sludge reduction. Fazelipour et al. (2011) achieved a 50% of sludge reduction by dosing to a SBR 0.26 g chlorine/g TSS [13]. However, soluble COD removal efficiency decreased dramatically (from 95 to 56%). The problem of chlorine application, i.e. its disadvantage compared with other oxidants, is the production of chlorinated organic compounds.

Nevertheless, chlorine dioxide minimizes formation of chlorine-based by-products [14] and it is a more powerful oxidant than chlorine. In the bibliography, only the paper by Wang et al. (2011) dosing chlorine dioxide to reduce sludge production has been found. These authors obtained maximum sludge disintegration at 10 mg ClO_2/g dry sludge for 40 min. ClO_2 oxidation was carried out in a SBR for excess sludge reduction (a efficiency

of 58% was achieved) without significantly harming the bioreactor performance [15]. Chlorine dioxide oxidizes partially the bacterial cells, what implies cell disintegration. This mechanism coupled with cryptic growth drives to reduction of the sludge production.

Summarizing, different oxidants and ultrasounds have been applied to enhance sludge disintegration and cryptic growth in view to the reduction of the sludge produced. Firsts papers hardly paid attention to the worsening of the effluent quality and the high reduction percentage have to be reconsidered by diminution of the soluble COD removal efficiency. Besides, more research about the use of chlorine dioxide for reduction of sludge production is necessary, since only a paper has been found in the bibliography, where promising results were reported. The economical feasibility of the process depends on the oxidant cost and in this way chlorine dioxide could compete with ozone and ultrasounds without the drawbacks of the chlorine.

In our work, different doses of chlorine dioxide were tested in order to study the reduction of the sludge and the consequences on the process performance and on cell viability. In addition, a direct dosing of ClO_2 to the SBR is compared with chlorine dioxide dosing to a part of the sludge in a separated tank.

2. Materials and methods

2.1 Simulated wastewater and chlorine dioxide

The SBRs feed solution consisted of 180 mg/L of peptone bacteriological, 180 mg/L of meat extract (both of Cultimed, Panreac) and 24.5 mg/L of tri-sodium phosphate 12-hydrate (Panreac). Chemicals were dissolved in tap water. COD of the simulated wastewater was 400 mg/L.

3000 mg/L of chlorine dioxide solutions were prepared mixing Twinoxide reagents A (sodium chlorite) and B (sodium bisulphate) from Brenntag. Different volumes from these solutions were added to establish the aimed chlorine dioxide dose in the SBR. These doses were referred to the biomass concentration in terms of Total Suspended Solids (TSS). In this way, doses of 10, 5 and 2 $mgClO_2/gTSS$ were tested in the first series of experiments.

2.2 Preliminary jar-tests

Previously to the SBR experiments, different chlorine dioxide concentrations (25, 10, 5 and 2.5 $mgClO_2/gTSS$) were mixed with activated sludge in a jar-test apparatus from Selecta. The aim of these tests was to select the range of chlorine dioxide concentration and the contact time for the further study in the SBRs.

Two contact times were tested (20 and 90 min). After the reaction time the suspended solids concentration and the supernatant turbidity after 30 minutes settling were measured in order to evaluate the efficiency of the cell disruption caused by chlorine dioxide. These

results were compared with those measured in the original activated sludge sample to study the effect of the chlorine dioxide on the sludge. The increase in the supernatant turbidity indicates an increase cell lysis.

2.3 Laboratory SBRs and experimental procedure

In the first series of experiments (named Experience 1) two identical SBRs were operated in parallel (Fig. 1) and fed with the same simulated municipal wastewater in order to study the effect of three chlorine dioxide concentrations (10, 5 and 2 mgClO_2/gTSS) that were added directly to one of the reactor (SBR 1) once a day. The other reactor (SBR2) was used as control SBR (no addition of chlorine dioxide).

Once the chlorine dioxide dose was chosen, a second series of experiments was carried out operating three SBRs in parallel. The same chlorine dioxide concentration was incorporated into two of them. In the SBR 1, 25% of the mixed liquor was pumped to a separated tank where the oxidant was dosed. In the SBR3, the oxidant was directly mixed with the sludge in the anoxic reaction phase. Finally SBR2 was used as control SBR. In this way, the effect of two different dosing strategies on the process performance was studied. In both cases, the oxidant volume to be dosed was previously calculated according to the measured TSS. As explained in sub-section 2.1 chlorine dioxide was added from a previously prepared solution.

The total (V) and the reaction (V_R) volumes of each SBR were 10 and 6 L, respectively. The volume of the feed tank was 80L. Table 1 illustrates for each experience the operation strategy.

Table 1. Strategy for chlorine dioxide addition in both experiences.

Reactor	Experience 1	Experience 2
SBR1	ClO_2 dosed directly to the reactor once a day	ClO_2 dosed in a separated tank mixing it with 1.5L of sludge withdrawn from the SBR (25% of sludge). Addition was carried out once a day.
SBR2	No chlorine dioxide addition	No chlorine dioxide addition
SBR3	------	ClO_2 dosed direct to the reactor once a day

Filling and draining of the SBRs were carried out with peristaltic pumps (D-25V from Dinko). Mixing was provided by a Heidolph mechanical stirrer. Air was supplied by

means of air blowers (EHEIM 400) and it was transferred through porous ceramic diffusers located in the reactors.

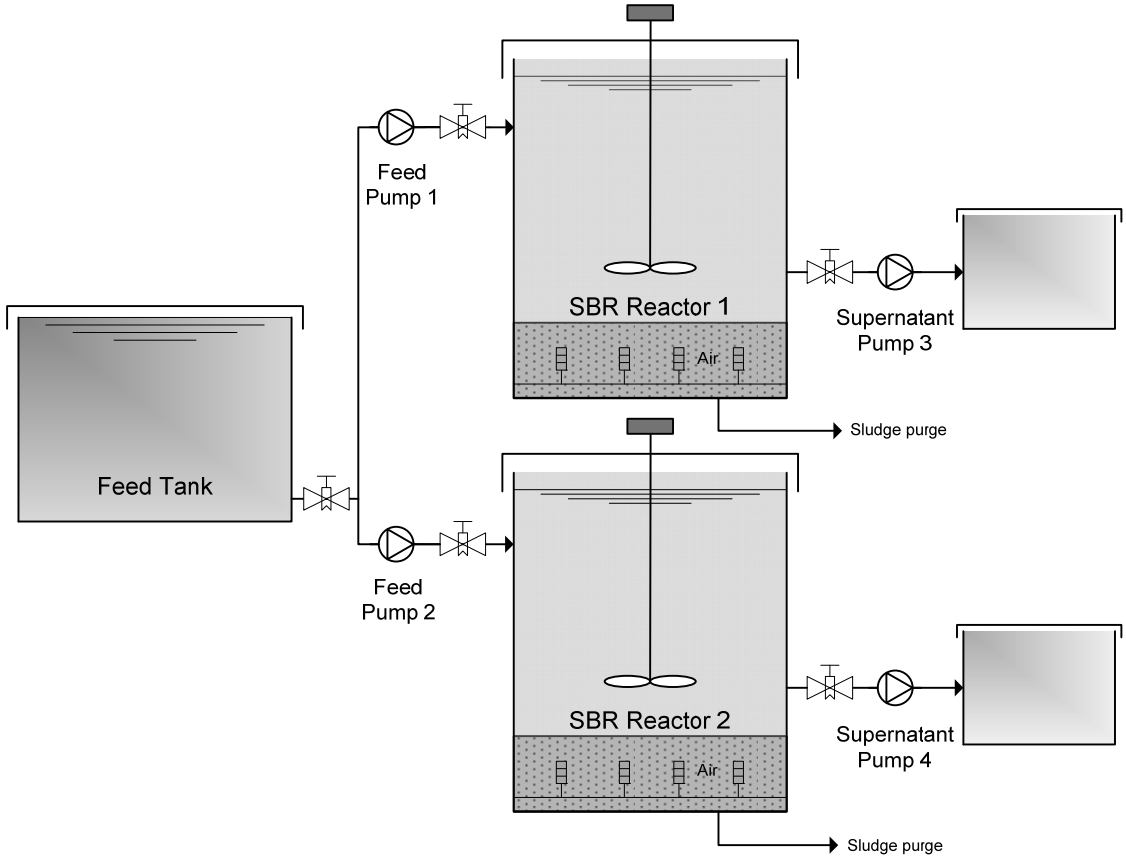

Fig. 1. SBRs pilot plants used in the experiments of the Experience 1.

The SBRs were seeded with activated sludge taken from a municipal wastewater treatment plant (WWTP) before each experiment at a particular ClO_2 dose. In all the cases, the acclimation period to the simulated wastewater was very short (4 days). Experiments were started when TSS concentration was around 2.5 g/L. In this way, sludge characteristics were practically identical before the different tests and results were not influenced by the initial conditions.

The operation of the SBRs in both series of experiences was always carried out according to the data of Table 2. The volume exchange ratio (VER) is defined as the quotient between the fill volume and the reaction volume. The hydraulic retention time is defined for SBR as in continuous flow activated sludge systems (V_R/Q).

Table 2. Strategy of SBR operation: phases duration and operating parameters.

Cycle steps	**Duration**
Anoxic fill phase	0.5 h
Anoxic reaction phase	0.5 h
Aerobic reaction phase	5.2 h
Settling phase	1.5 h
Draw phase	0.2 h
Idle phase	0.1 h
Total cycle time (T_C)	8 h
Volume exchange ratio (VER)	1/2
Hydraulic retention time (HRT)	16 h

Sludge withdrawals were performed periodically, draining the volume of mixed liquor previously calculated for achieving a concentration of TSS of 2.5 g/L.

2.4 Analysis

COD was determined by means of cell tests from Merck, the standard deviation of the method was ± 1.2 and ± 5.3 mg/L for the ranges 10–150 and 25-1500 mgCOD/L, respectively. TSS and volatile suspended solids (VSS) were measured following APHA [16]. Conductivity and pH were determined with EC-Meter (GLP-31+) and pH-Meter (GLP-21+) from CRISON, respectively. Turbidity was measured with a DINKO turbidimeter D-112. It was measured with an accuracy of ±2 NTU.

Proteins and carbohydrates concentrations were measured by BCA and Anthrone methods, both with an accuracy of 2%. Bovine serum albumin (BSA) (Sigma-Aldrich) and glucose (Panreac) were used as the protein and carbohydrate standards, respectively. Quant-itTM dsDNA HS (Invitrogen) assay kit was used to determine the DNA concentration in the supernatant.

The LIVE/DEAD® BacLight™ bacterial viability kit (Molecular Probes) was used for the estimation of the membrane integrity and total count of bacteria (viable/intact plus dead/damaged bacteria). It contains two nucleic acid stains. The green fluorochrome (Syto 9) is a small molecule that can penetrate intact plasma membranes while the larger red fluorochrome (propidium iodide) penetrates only compromised membranes [17]. Viable cells result in green colour while damaged cells result in red colour. The samples were evaluated with a BX50F microscope (Olympus, Tokyo, Japan) equipped with a 100-W high-pressure mercury lamp. The image analysis software used to analysis of the stained samples was BioImageL™ v. 2.1 [18]. The number of images taken for every sample was 20. Results were expressed by the average value of damaged cells and the uncertainty. This statistical parameter was calculated as the standard deviation divided by

the square root of the number of samples.

Trihalomethanes were determined by means of gas chromatography. A solution of 200 μgTHM/L was prepared based on trihalomethane calibration mix 200 μg/mL in methanol (Supelco). Then a liquid-liquid extraction was carried out with hexane, and later the organic phase was measured in an Electron Capture Detector (ECD) from Agilent Technologies 6850 GC.

3. Results

3.1 Preliminary tests

Preliminary experiments consisting of mixing activated sludge with different chlorine dioxide concentrations in jars, as explained in materials and methods section, were carried out to select the working chlorine dioxide concentration range to be applied in the SBRs experiences. Results are showed in Fig. 2.

The TSS concentration of the raw sludge was 3.65 g/L. It can be observed that the decrease in the TSS varied between 7 and 12% for the different chlorine dioxide doses. The highest tested chlorine dioxide dose (25 mgClO_2/gTSS) hardly increased the sludge disintegration in comparison with lower doses. Thus, doses of 10, 5 and 2.5 mgClO_2/gTSS were selected for the further experiments in the SBRs.

It has to be commented that the lysis phenomenon did not occurred at the expected extent, but it was thought that a daily addition of chlorine dioxide to the SBRs reactors at the selected doses could produce the desired disintegration effect on the biomass at a longer term.

Results were very similar for the two tested contact times. In this way, 20 minutes was adopted as contact time in the test in that chlorine dioxide was added to a withdrawn volume of the SBR sludge in a separated tank (second series of experiments).

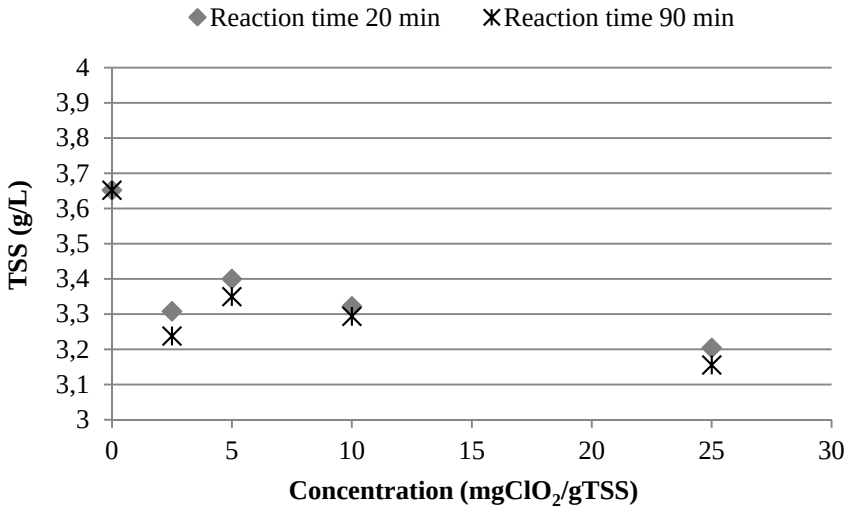

Fig. 2. TSS concentrations after mixing sludge with different ClO_2 doses in jar-test.

3.2 First series of experiments: effect of the ClO_2 concentration on biomass and process performance

In Table 3, the columns labeled as SBR_0 show the effluent characteristics of both reactors, SBR1 and SBR2, before the addition of ClO_2 (operating time=0). It has to be mentioned that effluents of both reactors had the same characteristics since they were seeded with the same activated sludge and they were fed with the same simulated wastewater. This point was very important in order to start the chlorine dioxide addition with identical conditions in the reactors. The applied dose in the SBR 1 is indicated in the table next to the SBR number. Thus, SBR1(10) means that the dose added was 10 $mgClO_2/gTSS$. As stated in materials and methods section, SBR2 was the control reactor.

Table 3 shows a summary of raw and treated wastewater characterization from both reactors for the three studied ClO_2 doses. Analyzed samples the last operating day are also shown in the table.

With a dose of 10 $mgClO_2/gTSS$, deterioration in the process performance was gradually observed. Thus, the final COD of the SBR1 effluent was 160 mg/L, what means that COD removal performance was reduced down to 60%. This was due to an excess of cell disruption what implied an accumulation of cell debris (a final protein concentration in treated wastewater of 38 mg/L was measured). The same phenomenon in lower extent was detected with a dose of 5 $mgClO_2/gTSS$. Final concentrations of COD and proteins in the treated effluents were 74 and 13 mg/L, respectively. Thus, experiments with 10 and 5 $mgClO_2/gTSS$ were stopped after 20 days.

As it can be observed, the tested chlorine dioxide dosage entailing the minimal diminution in the process performance was 2 $mgClO_2/gTSS$. In this way, the final COD measured value in the SBR effluent after 22 days was 30 mg/L. Besides, protein concentration was always lower than 10 mg/L. These results contrast with those obtained in the tests with 10 and 5 $mgClO_2/gTSS$ explained above. In this way, these two concentrations were discarded for further studies.

Table 3. Characteristics of the SBR effluents at the beginning and at the end of the tests with chlorine dioxide doses of 10, 5 and 2 $mgClO_2/gTSS$.

	SBR_0	SBR1(10)	SBR2	SBR_0	SBR1(5)	SBR2	SBR_0	SBR1(2)	SBR2
	Initial	Final	Final	Initial	Final	Final	Initial	Final	Final
pH	7.5	7.9	7.5	7.8	8.1	7.3	7.8	7.8	7.6
Conductivity (μS/cm)	1195	1442	1167	1180	1418	949	1187	1201	1191
COD (mg/L)	16	160	19	15	74	14	12	30	13
C_{BSA} (mg/L)	< 10	38	<10	< 10	13	< 10	< 10	< 10	< 10

On the other hand, it should be noticed an increase in pH and conductivity of the treated wastewater. This is explained by the chemical reactions produced by the chlorine dioxide, which generate hydroxyl ions and chlorides [19].

Fig. 3 illustrates the mass of sludge drained from both SBRs during the operation in the experience with 2 mgClO_2/gTSS addition. Sludge masses were calculated by multiplying the drained sludge volume by its TSS concentration.

Except for the first sludge withdrawal, the mass of drained sludge was higher for SBR2, the control SBR, what implies a decrease in the sludge production in the reactor with addition of chlorine dioxide. Taking into account the sludge production during the test (22 days), a 20.2% of reduction in the sludge production was achieved in SBR1. This was due to cell lysis and cryptic growth of the microorganisms caused by the chlorine dioxide addition.

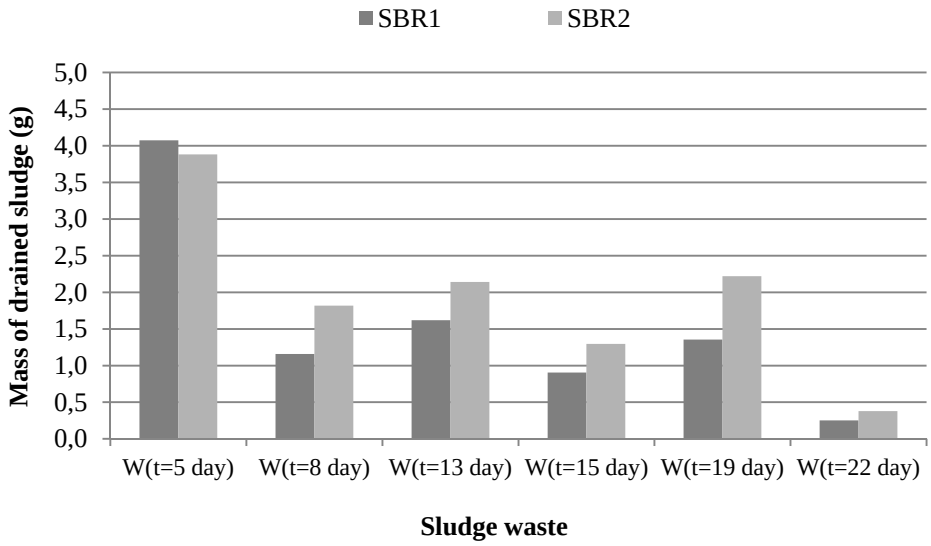

Fig. 3. Mass of drained sludge during the test with addition of 2 mgClO_2/gTSS.

As the achieved reduction was lower than that reported in the bibliography [15], it was decided to increase slightly the chlorine dioxide concentration to 2.5 mgClO_2/gTSS for the next series of experiments.

It has to be highlighted that trihalomethanes concentration in the effluents of SBRs with chlorine dioxide addition was below the ECD detection limit (0.1μg/L), which confirms the lack of THMs formation reported in the literature [20].

3.3 Second series of experiments: comparison of addition of chlorine dioxide to the reactor and to recycled sludge

In this experience 3 SBRs were operated in parallel and fed with simulated municipal wastewater as explained in materials and methods section. The three SBRs were seeded with sludge taken from the same MWWTP. Tests with chlorine dioxide began once it was checked that conditions were identical in all the reactors. The starting TSS concentration

before the chlorine dioxide addition was of 2.5 g/L in the three reactors. The concentration of added chlorine dioxide was the same (2.5 mgClO_2/gTSS) in the reactors SBR1 and SBR3. The difference between both reactors was the chlorine dioxide addition point. Meanwhile the oxidant was directly added to the SBR 3 during the anoxic phase, chlorine dioxide was dosed in a separated tank to a third of the sludge volume in SBR 1. The contact time in the separated tank for mixing the oxidant with the SBR withdrawn sludge was 20 minutes, as a result of the preliminary tests.

Fig. 4 shows the sludge mass withdrawn from the three reactors during the experience. It has to be mentioned that the amount of sludge drained was the calculated for re-establishing in the three reactors a TSS concentration of 2.5 g/L. Thus, information about the sludge production in the reactors can be obtained.

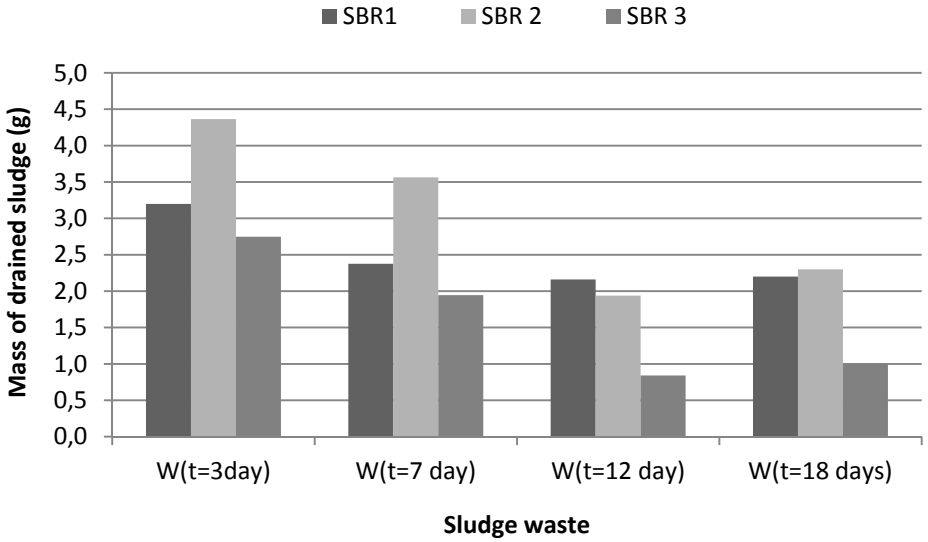

Fig. 4. Mass of sludge drained in the experiment comparing the addition point of the chlorine dioxide (2.5 mgClO_2/gTSS).

It can be observed that SBR 3 is the reactor with the lowest sludge production, i.e. the reactor from which less mass of sludge had to be drained to re-establish the initial TSS concentration. The highest sludge production occurred in the reactor 2, as expected. In this case, only in the third sludge draining the withdrawn mass was very similar to that of the SBR 1. This was due probably to sludge accumulation on the reactor walls, what was not observed in both reactors with addition of chlorine dioxide. It has to be highlighted that the reaction volume was of 6 L, what means that a small sludge loss (for example accumulation of sludge on reactor walls) could influence the results. It has to be commented that the percentage of VSS remained around 90% in the three reactors; thereby no mineralization was observed.

If masses of drained sludge are added, a reduction of 18.3% and 46.3% in SBRs 1 and 3, respectively, is achieved.

However, it should be checked if disintegration was followed by bacteria cryptic growth and, consequently, if the process performance did not diminished. In this way, Table 4 shows the characteristics of the treated wastewater of the three SBRs at the beginning and at the end of the experience.

Table 4. Characteristics of the treated wastewater of the three SBRs at the beginning and at the end of the second series of experiments (two addition points, dosage of 2.5 mgClO_2/gTSS)

	SBR1		SBR2		SBR3	
	Initial	Final	Initial	Final	Initial	Final
pH	7.8	8	7.9	7.1	7.8	8.1
Conductivity (µS/cm)	1190	1421	1170	1162	1210	1438
COD (mg/L)	10	18	10	17	10	42
Turbidity (NTU)	0.32	1.90	0.23	0.90	0.23	2.43

As stated above the initial conditions for the three SBRs were practically identical. COD of the treated wastewater was 10 mg/L (without ClO_2 addition). This very low value can be obtained due to the simulated wastewater composition. At the end of the experience, it can be stated that effluents from the SBRs 1 and 2 have similar COD values; meanwhile deterioration in the quality of the effluent from SBR 3 is observed. That means that addition strategy influenced on the sludge disintegration. The addition to a separated tank led to a more controlled cell disruption, what implied a better equilibrium between disintegration and cryptic growth.

However, it is considered that a COD of 42 mg/L still means that effluent has a certain quality, since the discharge standard limit is 125 mg/L. Decreasing the sludge production in a 46.3% at the expense of increasing COD up to 42 mg/L was considered an interesting result.

The increase in COD of treated wastewater from SBR 3 implied an increase in the turbidity as well. On the other hand, it should to be noticed the increase in the pH and in the conductivity as explained in the first series of experiences. This fact lead us to think about the possibility of alternating periods of time with and without chloride dioxide addition to avoid the accumulation of hydroxide and chloride ions in the effluents.

With the aim of studying deeply the SBRs flocs disintegration, proteins, carbohydrates and DNA were measured in the SBRs effluents.

Fig. 5 illustrates the protein concentration in mgBSA/L in the effluents from the SBRs.

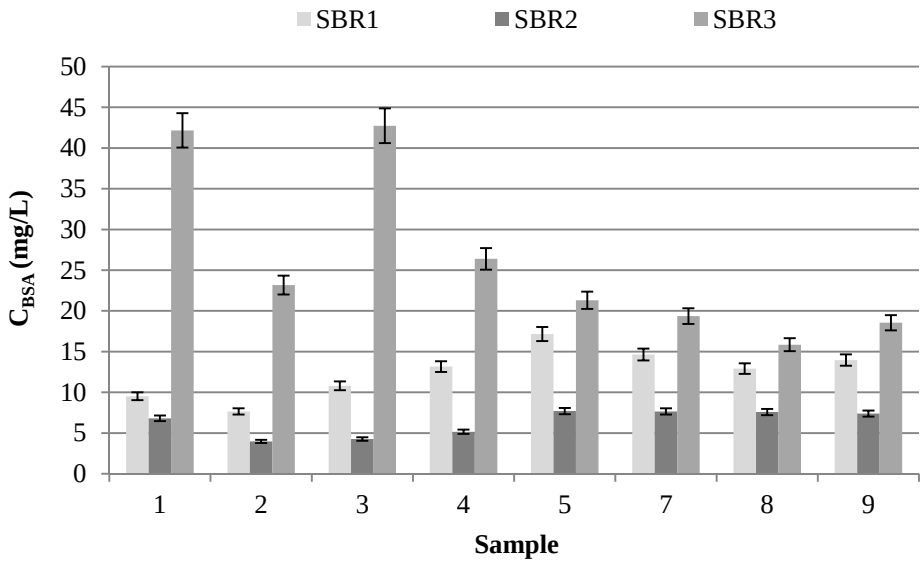

Fig. 5. Concentration of proteins (mgBSA/L) in the effluents from the SBRs in the second series of experiments (two addition points, dosage of 2.5 mgClO_2/gTSS)

It can be observed that protein concentration in SBR 2 (no chlorine dioxide addition) was practically constant during the experiment. The slight variation in the first operating days was due to changes in the biomass because of the feed with simulated wastewater. Anyway, protein concentrations ranged between 3.5 and 7.5 mg/L. Concerning SBRs 1 and 3, results showed clearly the effect of chlorine dioxide on the biomass disintegration since protein concentrations were higher than in the effluent from SBR 2. In SBR 3, protein increase occurs more quickly since chlorine dioxide is mixed with all the sludge in the reactor. In this reactor protein concentration decreased from sample 4, what means the enhancement of the cryptic growth.

For all SBRs, analyses of carbohydrates offered results below 1 mg/L for the samples 1 to 5. However, in the three last samples an increase in carbohydrate concentration was observed for the SBR 2 effluent. This can be related to the slight decrease in COD removal efficiency observed in the process (see Table 5). On the contrary, carbohydrate concentrations of the two SBRs with chlorine dioxide addition were always below 1.1 mg/L. This could be explained by a higher assimilation of carbohydrates in the cryptic growth.

Table 5. Carbohydrates concentration in the last effluent samples taken in the second series of experiments (two addition points, dosage of 2.5 mgClO_2/gTSS)

	Carbohydrates (mgGlucose/L)		
	Sample 7	Sample 8	Sample 9
SBR 1	0.54	1.00	1.10
SBR 2	3.06	3.66	5.83
SBR 3	0.37	0.10	0.58

Fig. 6 relates the measured DNA concentrations with the proteins content in the effluents from the three SBRs. DNA in the effluents indicates that cell lysis occurs. It was observed a direct relation between DNA and protein concentrations, what confirms that measured proteins come from the cellular material of the bacteria.

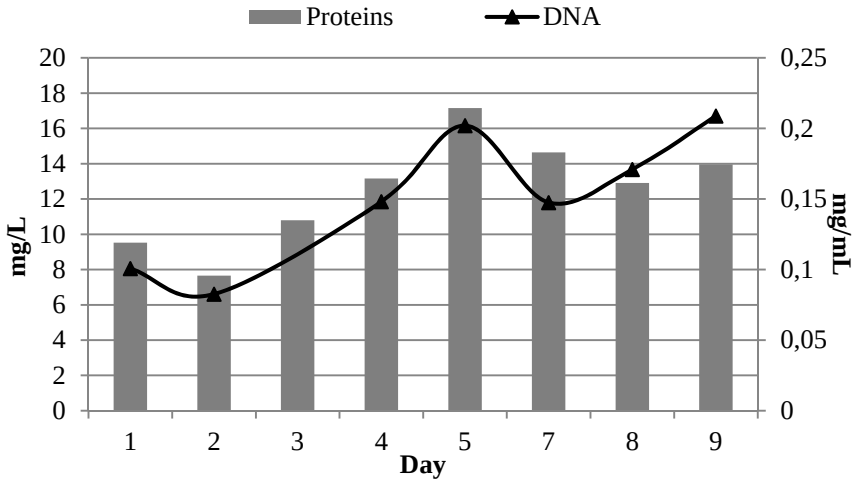

Fig. 6 (a). Evolution of proteins and DNA in effluent from SBR 1 (Experiment 2).

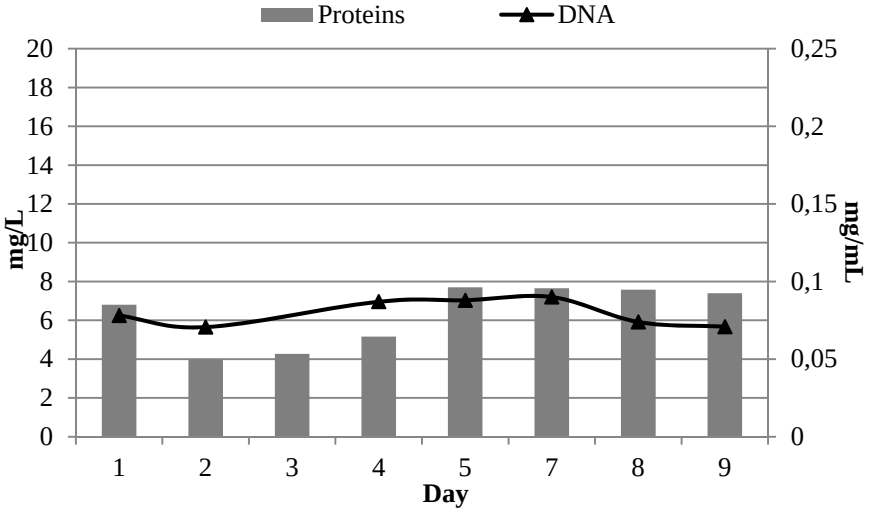

Fig. 6 (b). Evolution of proteins and DNA in effluent from SBR 2 (Experiment 2).

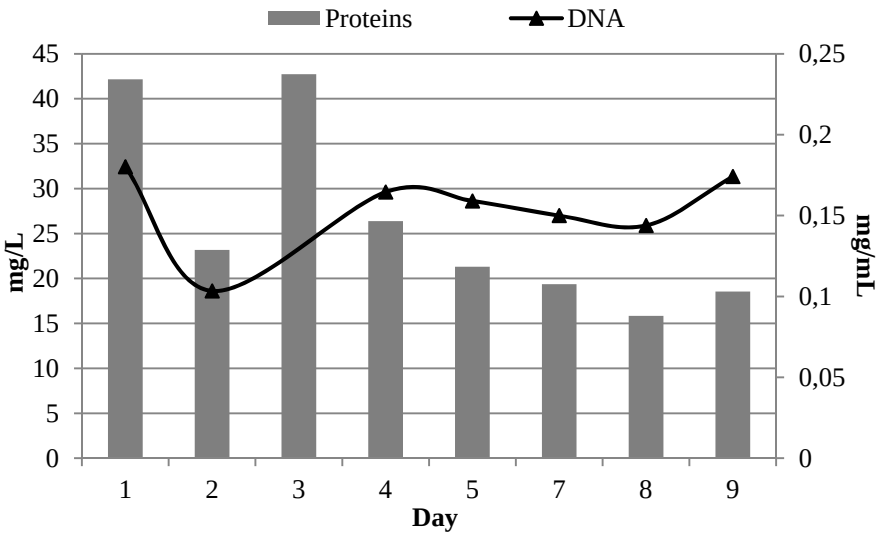

Fig. 6 (c). Evolution of proteins and DNA in effluent from SBR 3 (Experiment 2).

Finally, cellular viability tests were carried out. In Table 6, it can be observed that the effect of the chlorine dioxide on the cells is gradual. After 5 days of operation the percentage of dead cells is very similar in SBRs 1 and 2 (i.e. no effect of chlorine dioxide on the biomass was detected), meanwhile the percentage of dead cells is higher than 10% in SBR 3. However, after 18 days of operation similar results were observed in the two SBRs with chlorine dioxide addition. Almost a 50% of the cells were dead.

In spite of the dead cells proportion, COD removal efficiency was high as explained above. This is due to the biodegradability of the simulated wastewater. With municipal wastewater TSS concentration should be increased to achieve an appropriate mass load to maintain the desired COD removal efficiency. These results lead us to think that the optimal chlorine dioxide dose will depend not only on the TSS concentration but also on the wastewater characteristics.

Table 6. Mean values measured of dead cells in the three SBRs in the second series of experiments.

	Day 5		Day 18	
	Mean (%)	Uncertainty	Mean (%)	Uncertainty
SBR 1	3.9	1.5	46	7.3
SBR 2	5.6	2.1	8	2
SBR 3	11	2.8	49	7.6

As an example, in Fig. 7 images of a representative microscope picture are shown. On the left part, pictures correspond to samples of the three SBRs taken simultaneously in the fifth operating day. On the right part, pictures were taken in the day number 18.

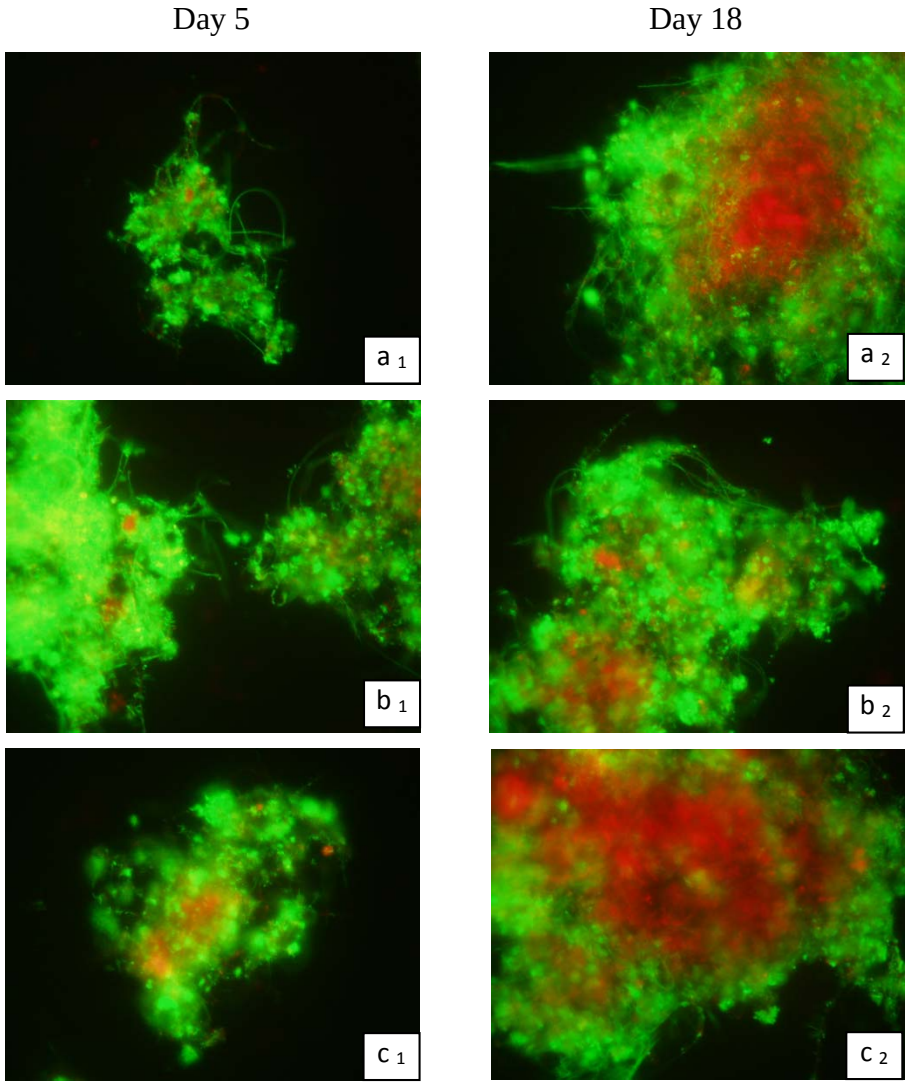

Fig. 7. Microscopic images of viability tests of activated sludge from SBR 1 (a), SBR 2 (b) and SBR3 (c) after 5 and 18 days of SBRs operation, 400X.

4. Conclusions

Chlorine dioxide has been tested in laboratory SBRs with the aim of reducing the production of sludge by cell lysis and cryptic growth. Doses of 5 and 10 mgClO_2/gTSS led to deterioration of the biological process. However, a dose of 2 mgClO_2/gTSS hardly reduced the COD removal efficiency and drove to a diminution of 20% in the sludge production. Increasing the ClO_2 dose up to 2.5 mgClO_2/gTSS implied a considerably increase in the reduction of the sludge production (up to 46%). This result was obtained when the oxidant was added directly to the reactor. A lower reduction of the sludge production was observed when the oxidant was mixed with a part of the SBR activated sludge in a separated tank.

The results of the SBR effluent analysis, when 2.5 mgClO_2/gTSS were added, confirmed a slight diminution in the COD removal efficiency by presence of proteins and DNA coming from the cell disintegration. However, these values remained more or less constant after the initial increase, once the cryptic growth occurs. Carbohydrates concentrations were very low.

Viability tests showed that almost a 50% of the cells were dead at the end of the experience with 2.5 mgClO_2/gTSS. In spite of it the process performance was correct. Further experiences with municipal wastewater at larger scale should be carried out for checking if the diminution in living cells entails deterioration of the treated wastewater.

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