Alexandria Engineering Journal

Combined effects of cadmium and zinc on both sequencing batch reactor and continuous activated sludge

M. T. Sorour and A. M. Sayed-Ahmed
Sanitary Eng. Dept., Faculty of Engineering, Alexandria University, 21544 Alexandria, Egypt
Email: Sorourt@hotmail.com

This study aims to investigate the performance and treatment capability of sequencing batch reactor and activated sludge systems under heavy metals shock loads. The combined effects of cadmium and zinc on both systems were studied. Two pilot plant units, one for each system were used to study the effect of gradually increasing both cadmium and zinc on the treatment process. Batch tests were also performed to study the effect of both cadmium and zinc shock loads on the acclimated sludge that collected from each pilot plants. The results of the pilot plant units showed that the efficiency of COD removal decreases under the gradual increase of heavy metals and that this efficiency was higher in the sequencing batch reactor pilot plant than the activated sludge pilot plant. Results of batch tests showed that the efficiency of COD removal of acclimated sludge collected from each pilot plant was higher than the normal sludge collected from both systems before adding metals. Similarly this efficiency was higher in the sequencing batch reactor pilot plant than the activated sludge pilot plant operated under the same conditions.

يهدف هذا البحث إلي دراسة عمل و كفاءة المعالجة البيولوجية لكل من الحمأة المنشطة التقليدية و المفاعلات البيولوجية التتابعية تحت تأثير تركيزات من المعادن الثقيلة. و في هذا البحث تم دراسة التأثير المشترك لعنصري الكادميوم و الزنك علي كفاءة المعالجة بالطريقتين المذكورتين. و قد تم إنشاء وتشغيل نموذجين معمليين الأول لنظام الحمأة المنشطة التقليدية و الثاني لنظام المفاعلات البيولوجية التتابعية و أجريت مجموعتين من التجارب. المجموعة الأولى تشمل تجارب حالة الثبات للنظامين وفي هذه المجموعة تم دراسة تأثير الزيادة التدريجية لعنصري الكادميوم والزنك على كفاءة نظامي المعالجة. و المجموعة الثانية تشمل تجارب أحمال الصدم و قد أجريت هذه المجموعة من التجارب على مفاعلات صغيرة وذلك في نهاية كل مرحلة من مراحل حالة الثبات وذلك باستخدام حمأة من كل نموذج تجريبي على حده وتوزيعها بالتساوي مع تثبيت جميع ظروف التشغيل ما عدا تغيير تركيز عنصري الكادميوم والزنك. وقد أظهرت نتائج التجارب التي أجريت على نموذجي التجارب أن الزيادة التدريجية لعنصري الكادميوم والزنك لها تأثير سلبي على كفاءة إزالة ال COD في كل من النظامين المذكورين بشكل عام غير أن في جميع الحالات كانت كفاءة المفاعلات البيولوجية التتابعية أعلى من الحمأة المنشطة. كما أظهرت نتائج تجارب أحمال الصدم والتي أجريت على ال Batch Reactors أن التأثير السلبي لعنصري الكادميوم والزنك على كفاءة إزالة ال COD يزيد بزيادة تركيز العنصرين المذكورين وكذلك أن معامل السمية MT يزيد لنفس السبب. غير أن هذا التأثير السلبي يكون أقل في حالة استخدام الحمأة التي تأقلمت على تركيزات من عنصري الكادميوم والزنك في نموذجي التجارب.

Keywords: Activated sludge, Heavy metal shock loads, Metal toxicity, Sequencing batch reactor

1. Introduction

The presence of heavy metals in wastewater causes a two fold problem to the environmental engineer: First, they may be present at a higher than acceptable concentrations when treated wastewater is discharged into receiving water bodies and can thus cause damage to aquatic and plant life and to humans as well if these concentrations are not reduced to acceptable drinking water standards after water treatment. Second, they may cause a reduction in the efficiency of wastewater treatment plants [1]. Because nearly all municipal wastewater treatment systems and many industrial wastewater treatment processes employ some form of biological treatment, the need for studying the effect of heavy metals on biological treatment is clear in order to increase the level of understanding these effects. Sequencing Batch Reactor (SBR) has become one of the most popular modifications of Activated Sludge (AS) systems especially in small and medium wastewater

© Faculty of Engineereing Alexandria University, Egypt

treatment plants [2]. Whereas the SBR process has the capability to receive shock organic loads, little information about the effects of heavy metals shock loads on the SBR process can be found in literature [3, 4]. Combined effects of cadmium and zinc are examined in this study. Cadmium is obtained as a by-product of refining operations associated with the extraction of other metals, particularly zinc. The metal plating industry and fossil fuel burning expel the largest quantities of cadmium and zinc. Cadmium coatings are used to protect against corrosion for steel, brass, copper, and other alloys [5].

Previous studies that were carried out to investigate the effects of cadmium and zinc on the AS process indicated that the toxicity of metal is related to its accumulated concentration in the biomass. No effect was noticed until a threshold concentration of metal in the sludge was reached at which the system began to be adversely affected [6,7].

The primary intent of this study is to investigate the combined effects of cadmium and zinc on both AS and SBR processes. The outcome of this study would be helpful to design engineers and treatment plant operators in solving treatment problems resulting from heavy metal toxicity.

2. Materials and methods

To determine the combined effects of cadmium and zinc on the performance of both AS and SBR processes, laboratory pilot plant units were operated at steady state conditions, keeping all environmental variables constant with the exception of influent cadmium and zinc concentrations. The experimental work was conducted by operating two pilot plants in parallel. The first pilot plant was operated as a continuous AS flow. The second was operated as a SBR. Four runs were carried out to study the effect of gradually increasing the percentage of cadmium and zinc on the performance of each pilot plant. In addition, batch tests were conducted to study the effect of cadmium and zinc shock loads on the acclimated sludge collected from both AS and SBR pilot plants after each run.

2.1. Pilot plants

The two pilot plants used in this study were constructed and operated at the laboratory of the Sanitary Engineering Department, Faculty of Engineering, Alexandria University.

2.1.1. The AS pilot plant

As shown in fig. 1**,** the system consists of two basins. The first is a rectangular aeration tank (volume of aeration tank = 23 litters), the second is a final settler tank (volume of settler = 6.5 litters). The pilot plant was provided with two pumps. The first pump was used to feed the synthetic sewage to the aeration tank, the second was used to return sludge from the final settling tank to the aeration tank. The amount of air delivered to the aeration tank was sufficient to maintain the Mixed Liquor Suspended Solids (MLSS) in suspension and to maintain a dissolved oxygen level of approximately 2 mg l^{-1}. The influent and return sludge flow rates were equal to 40 l d^{-1} ($Q_{in} = Q_R = 40$ l d^{-1}). The waste sludge was taken from the MLSS to maintain the sludge age (θ_c) at 10 days.

2.1.2. The SBR pilot plant.

The SBR pilot plant consists of one rectangular basin, which was operated as both an aeration tank and a final settler in the time sequence. The total volume of SBR reactor was 30 liters. As shown in fig. 2-a, the pilot plant was provided with two pumps. The first pump was used as a feeding pump in the fill phase of operation (dump fill). The other one was used to draw treated water at the end of the operation cycle. The amount of air delivered in the SBR was sufficient to maintain the MLSS in suspension and to maintain a dissolved oxygen level of approximately 2 mg l^{-1}. Automatic programmable timer (XT table top timer, chron trol cooperation, USA) was used in order to control the cycles of operation. Fig. 2-b shows the operation cycle of SBR. The influent and effluent flow rates were 15 and 14 liter per cycle, respectively. The waste sludge was taken from the MLSS to maintain θ_c at 10 days. The volumes of mixed liquor before and after fill were 15 and 30 liter, respectively.

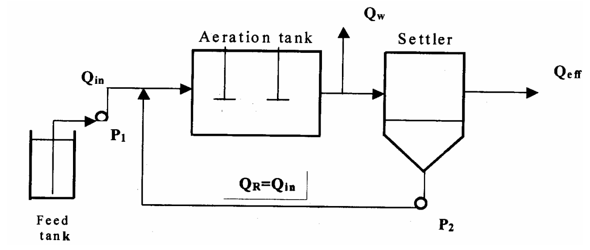

Fig. 1. Activated sludge pilot plant.

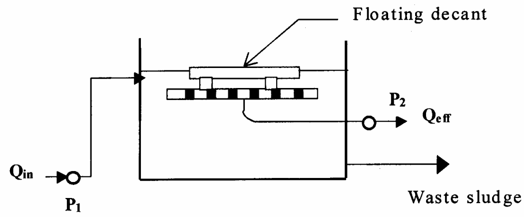

Fig. 2-a. Sequencing batch reactor (SBR) pilot plant.

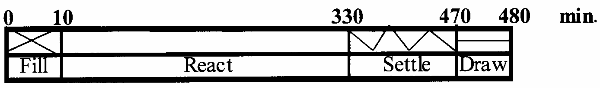

Fig. 2-b. Operation cycle of SBR.

The volume exchange ratio (V_E) was 50%, where $V_E = \dfrac{\text{volume of feeding wastewater}}{\text{total volume of the reactor}}$.

2.2. Synthetic sewage

Synthetic sewage was used in this study as an influent wastewater for both AS and SBR pilot plants. The synthetic sewage was prepared according to ref. [7]. The stock solution was prepared first as follows: Dissolve 40 g l^{-1} of glucose; 11.65 g l^{-1} of $Na_3PO_4.12\,H_2O$; and 8.8 g l^{-1} of $(NH_4)_2SO_4$ in one litter tap water. Synthetic sewage can be prepared by diluting the stock solution with tap water (1 - 100). The synthetic sewage was daily prepared fresh. The diluted solution has an average COD concentration equals to 360 mg l^{-1}. The stock solutions concentration of cadmium and zinc were 100 mg l^{-1} by dissolve cadmium chloride and pure zinc metal, respectively in distillated water. These stock solutions were used as a source of metals in synthetic feed [8].

2.3. Start-up procedure

Initially the AS and SBR pilot plants were seeded with sludge wasted from AS treatment plant in Kafer El Dawwar. The sludge was collected from the return sludge pump. The start up period was 10 days. The operation conditions were constant at the end of the start up period. After that period the sludge was wasted from the aeration tank to achieve the desired θ_c [9].

2.4. Experimental plan

The experimental plant of this study was divided into two parts. First part includes steady state operation of both AS and SBR pilot plants. Second part includes batch tests using collected sludge from each system of operation.

2. 4.1. Steady state operation

Steady state operation aims to study the combined effects of cadmium and zinc on both AS and SBR pilot plants. The experimental work was conducted by operating two pilot plants in parallel. The first pilot plant was operated as a continuous flow AS pilot plant. The second was operated as a SBR pilot plant. Four runs were carried out. All operating conditions in each run were kept constant with the exception of influent cadmium and zinc concentrations. Metal doses in the synthetic feed were changed at every run. Run I, control run, was performed with cd/ zn dose 0.0/0.0 mg l^{-1}, run II was performed with a cd/ zn dose 2.5/2.5 mg l^{-1}, run III was performed with cd/ zn dose 5.0/5.0 mg l^{-1} and in run IV the cd/zn dose was increased to 10.0/10.0 mg l^{-1}. The duration of each run was at least 10 days. At the end of each run, sludge was taken from each system to perform batch tests.

2. 4.2. Batch test

Batch tests were performed to evaluate the combined effects of cadmium and zinc shock loads on the acclimated sludge for both AS and SBR pilot plants after each run. At the end of Run I, Sludge I was collected form both AS and SBR pilot plants to carry out batch test I for both AS and SBR systems. The same was repeated for run II, run III and run IV, batch test II, test III and test IV were carried out respectively. In each batch test, eight reactors were used four reactors for AS and four reactors for SBR. Sludge collected from pilot plants was aerated with the synthetic feed in batch reactors. The duration of each batch test was about 4 hours. Conditions of batch tests are shown in table 1 [7, 10, 11].

2.5. Analytical techniques

All experimental measurements in steady state operation and batch tests were determined in accordance with the standards methods for the examination [8]. The Specific Oxygen Up Take Rate (SOUR) and Metal Toxicity (MT) were calculated at any batch test in each reactor according to the following equations [7]:

$$SOUR = \frac{OUR}{MLSS}$$

$$MT = 1 - \frac{SOUR}{SOURc}\,.$$

Where $SOUR_C$ is a SOUR in a control reactor.

3. Results and discussion

3.1.1. Performance of AS and SBR pilot plants under a cd/zn dose of 0.0/0.0 (run I)

After the initial start up period, the operating conditions of the AS and SBR systems were controlled to be constant during the steady state operation. The performance of both AS and SBR systems were recorded during the best period of steady state to measure the treatment efficiency of the systems. For both AS and SBR pilot plants, the average value of Food to Microorganisms (F/M) ratio (mg COD per day / mg MLSS) during steady state period was 0.41 d^{-1}. The COD removal efficiency for AS system ranged between 90.3% to 94.4% with an average value of 92.5 %. The COD removal efficiency for SBR system ranged between 91.7% to 97.2% with an averaged value of 94.8 %.

Previous results confirmed that the efficiency of COD removal in the SBR under the steady state operation is higher than of the AS system.

3.1.2. Batch tests on sludge I for as and SBR systems (test I for AS and SBR systems)

The sludge used in this test was collected from the pilot plant units called sludge I at the end of run I. Two batch tests were conducted in parallel to evaluate the combined effects of cadmium and zinc shock loads on the sludge I. Test I for AS was carried out using sludge collected from AS pilot plant. Test I for SBR was carried out for sludge collected from SBR pilot plant. The efficiency of COD removal and the MT were measured under different doses of metals (cd/ zn doses: 0.0/0.0; 2.5/2.5; 5.0/5.0 and 10.0/10.0 mg l^{-1}). Table 2 shows the summary of results of these tests. The relation between MT and cd/ zn dose for sludge I is shown in fig. 3. The relation between the cd/ zn dose and efficiency of COD removal is shown in fig. 4.

From fig. 3, it is clear that the MT of sludge I of SBR is higher than the MT of AS for cd/ zn doses of 2.5/2.5 and 5.0/5.0 mg l^{-1}. However for cd/ zn dose of 10.0/10.0 mg l^{-1} the MT of sludge I of SBR is lower than the MT of AS system.

Table 1
Conditions of batch tests

Reactor	1 (control)	2	3	4
Metal doses cd/zn (mg l^{-1})	0.0/0.0	2.5/2.5	5.0/5.0	10.0/10.0
Sludge volume (l)	1	1	1	1
Synthetic sewage volume (l)	1	1	1	1
Initial measurements	COD_{in}, MLSS and OUR			
Final measurements	COD_{eff} and OUR			

Table 2
The combined effect of cd/zn shock loads on sludge I for AS and SBR (test I)

	Sludge from AS pilot plant				Sludge from SBR pilot plant			
Parameter	Reactor 1 (control) 0.0/ 0.0	Reactor 2 cd/zn 2.5/2.5	Reactor 3 cd/zn 5.0/5.0	Reactor 4 cd/zn 10.0/10.0	Reactor 1 (control) 0.0/0.0	Reactor 2 cd/zn 2.5/2.5	Reactor 3 cd/zn 5.0/5.0	Reactor 4 cd/zn 10.0/10.0
F/M d^{-1}	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
E %	87%	83%	77%	53%	90%	88%	86%	80%
SOUR d^{-1}	0.288	0.240	0.170	0.082	0.442	0.276	0.233	0.211
MT	0.00	0.19	0.41	0.72	0.00	0.35	0.45	0.50

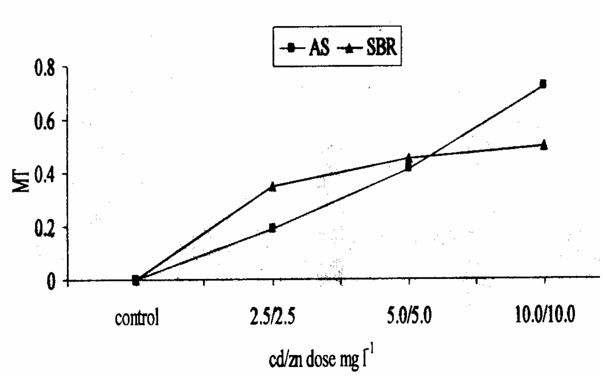

Fig. 3. Relation between MT and cdzn dose (test I).

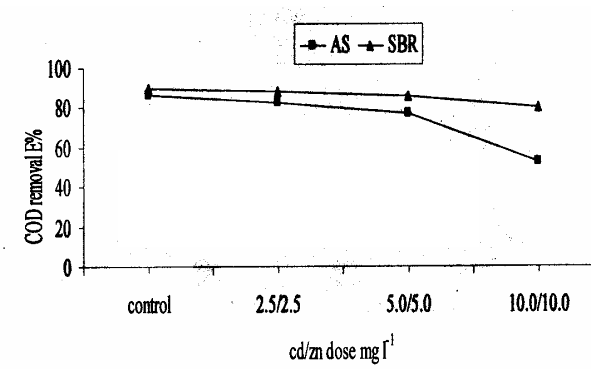

Fig. 4. Effect of cd/zn on the COD removal (test I).

It is also clear from fig. 4 that the efficiency of COD removal for sludge I of SBR system is higher than the efficiency of COD removal for sludge I of AS system under the same doses of cd/ zn. For example, E = 80 % for sludge I of SBR, where E = 53% for sludge I of AS, both under cd/zn dose 10.0/10.0 mgl^{-1}.

It is noted from these results that the efficiency of COD removal is decreasing under heavy metal shock loads for both systems and the sludge in the SBR pilot plant has higher ability to receive heavy metal shock loads than the sludge in the AS pilot plant.

3.2.1. Performance of AS and SBR pilot plants under a cd/ zn dose of 2.5/2.5 (run II)

After run I, the concentration of cd/zn dose in the synthetic feed was increased to 2.5/2.5 mg l^{-1} (run II). The performance of both AS and SBR systems were recorded during this period of operation to measure the treatment efficiency. For both AS and SBR pilot plants, the average value of F/M ratio (mg COD per day / mg MLSS) during steady state period was 0.45 d^{-1}. The COD removal efficiency for AS system ranged between 86.1% to 94.4% with an average value of 92.0 %. The COD removal efficiency for SBR system ranged between 88.9% to 94.4% with an average value of 93.6 %. These results also showed that the efficiency of COD removal in the SBR under a cd/ zn dose of 2.5/2.5 mg l^{-1} is higher than in the AS system.

3.2.2. Batch tests on sludge II for AS and SBR systems (test II for as and sbr systems)

The sludge collected at the end of run II was called sludge II. Two batch tests were conducted in parallel to evaluate the combined effects of cadmium and zinc shock on the sludge II. Test II for AS was carried out using sludge collected from AS pilot plant. Test II for

SBR was carried out using sludge collected from SBR pilot plant. The efficiency of COD removal and the MT were measured under different doses of metals (cd/zn doses: 0.0/0.0; 2.5/2.5; 5.0/5.0 & 10.0/10.0 mg l^{-1}). The summary of results of sludge II is shown in table 3. The relation between MT and cd/zn dose is shown in fig. 5. The relation between cd/zn dose and the COD removal is shown in fig. 6.

Fig. 5 shows that the MT of batch test for the acclimated sludge of SBR (Test II for SBR) is higher than the MT of the acclimated sludge of AS (Test II for AS) under cd/ zn doses of 2.5/2.5 and 5.0/5.0 mg l^{-1}. However, under cd/zn a dose of 10.0/10.0 mg l^{-1}, the MT was 0.50 for sludge II of SBR and 0.62 for sludge II of AS system.

It can be also concluded from fig. 6 that the efficiency of COD removal for sludge II of SBR system is higher than the efficiency of COD removal for sludge II of AS system under the same doses of cd/zn. For example, E = 81 % for sludge II of SBR, where E = 60% for sludge II of AS, both under cd/zn dose 10.0/10.0 mg l^{-1}.

3.3.1. Performance of AS and SBR pilot plants under a cd/ zn dose of 5.0/5.0 (run III)

After run II, the concentration of cd/zn dose in the synthetic feed was increased to 5.0/5.0 mg l^{-1} (run III). The performance of both AS and SBR systems were recorded during this period of operation to measure the COD removal of the systems. The average value of F/M (mg COD per day / mg MLSS) for

Table 3
The combined effect of cd/zn shock loads on sludge II for AS and SBR (test II)

Parameter	Sludge from AS pilot plant				Sludge from SBR pilot plant			
	Reactor 1 (control) 0.0/0.0	Reactor 2 cd/zn 2.5/2.5	Reactor 3 cd/zn 5.0/5.0	Reactor 4 cd/zn 10.0/10.0	Reactor 1 (control) 0.0/0.0	Reactor 2 cd/zn 2.5/2.5	Reactor 3 cd/zn 5.0/5.0	Reactor 4 cd/zn 10.0/10.0
F/M d^{-1}	0.21	0.21	0.21	0.21	0.25	0.25	0.25	0.25
E %	86%	80%	74%	60%	94%	90%	89%	81%
SOUR d^{-1}	1.133	0.958	0.782	0.434	0.514	0.374	0.324	0.257
MT	0.00	0.15	0.31	0.62	0.00	0.27	0.37	0.50

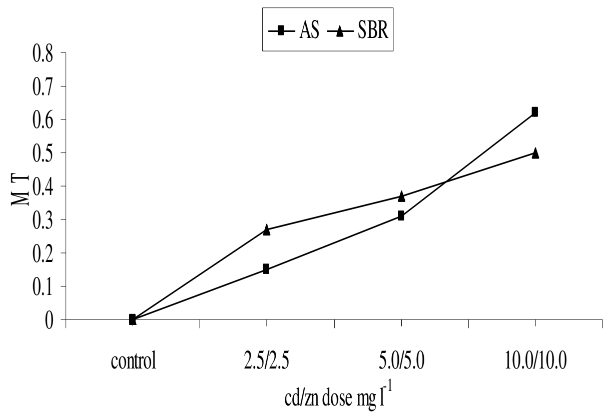

Fig. 5. Relation between MT and cd/zn dose (test II).

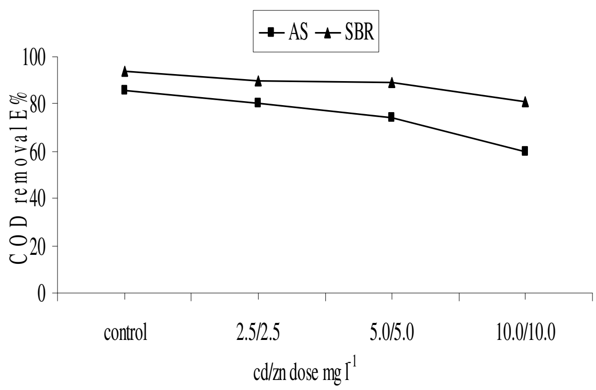

Fig. 6. Effect of cd/zn on the COD removal (test II).

both AS and SBR systems during steady state period was 0.41 d^{-1}. The COD removal efficiency for AS system ranged between 86.1% to 93.1% with an average value of 89.2 %. The COD removal efficiency of SBR system ranged between 91.7% to 94.4% with an average value of 92.5 %. It can be noted that the efficiency of COD removal in SBR is higher than in AS system.

3.3.2. Batch tests on sludge III for AS and SBR systems (test III for AS and SBR systems)

Tzo batch tests were carried out at the end of this run to evaluate the combined effects of cadmium and zinc shock loads on the sludgeIII. The efficiency of COD removal and the MT were measured under different doses of metals (cd/ zn doses: 0.0/0.0; 2.5/2.5; 5.0/5.0 and 10.0/10.0 mg l^{-1}). The summary of results of sludge III is shown in table 4. The relation between MT and cd/ zn dose is shown in fig. 7. The relation between cd/zn dose and COD removal is shown in fig. 8.

Fig. 7 indicates that the MT of batch test for the acclimated sludge of SBR (Test III for SBR) is lower than the MT of the acclimated sludge of AS for all cases. For example, the MT was 0.47 for sludge III of SBR and 0.50 for sludge III of AS both under cd/ zn dose 10.0/10.0 mg l^{-1}.

Table 4
The combined effect of cd/ zn shock loads on sludge III for AS and SBR (test III).

Parameter	Sludge from AS pilot plant				Sludge from SBR pilot plant			
	Reactor 1 (control) 0.0/0.0	Reactor 2 cd/zn 2.5/2.5	Reactor 3 cd/zn 5.0/5.0	Reactor 4 cd/zn 10.0/10.0	Reactor 1 (control) 0.0/0.0	Reactor 2 cd/zn 2.5/2.5	Reactor 3 cd/zn 5.0/5.0	Reactor 4 cd/zn 10.0/10.0
F/M d^{-1}	0.23	0.23	0.23	0.23	0.18	0.18	0.18	0.18
E %	91%	90%	86%	69%	91%	89%	86%	83%
SOUR d^{-1}	0.410	0.275	0.227	0.205	0.533	0.405	0.320	0.282
MT	0.00	0.33	0.45	0.50	0.00	0.24	0.40	0.47

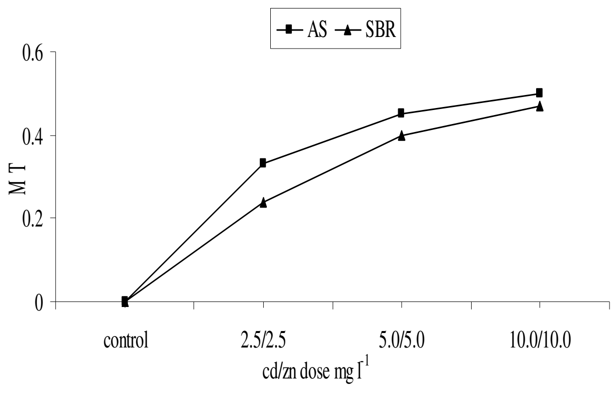

Fig. 7. Relation between MT and cd/zn dose Test III).

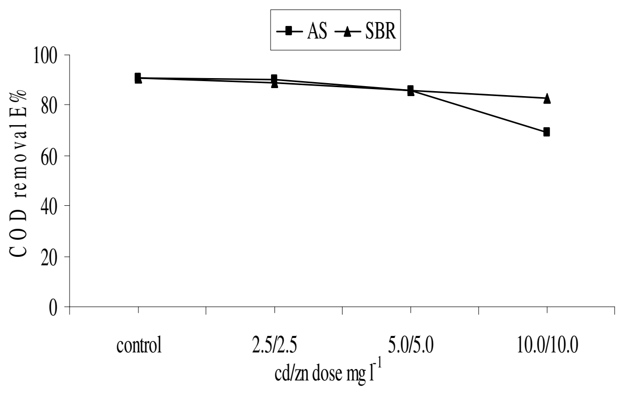

Fig. 8. Effect of cd/zn on the COD removal (Test III).

Fig. 8 shows that the efficiency of COD removal for the sludge III of SBR system is higher than the efficiency of COD removal for the sludge III of AS system under the same doses of cd/ zn. For example, E = 83 % for sludge III of SBR, where E = 69% for sludge III of AS, both under cd/zn dose 10.0/10.0 mgl^{-1}.

3.4.1. Performance of AS and SBR pilot plants under a cd/ zn dose of 10.0/10.0 (run IV)

At the end of run III, the concentration of cd/zn dose in the synthetic feed was increased to 10.0/10.0 mg l^{-1} (run IV). The performance of both AS and SBR systems were recorded during the steady state to measure the efficiency of treatment. The average value of F/M (mg COD per day / mg MLSS) for both AS and SBR systems was 0.47 d^{-1}. The COD removal efficiency for AS system ranged between 77.8% to 88.9% with an average value of 84.4 %. The COD removal efficiency for SBR system ranged between 86.1% to 90.3% with an average value of 87.5 %. Accordingly, the efficiency of COD removal in SBR is higher than in AS system.

3.4.2. Batch tests on sludge IV for AS and SBR systems (test IV for AS and SBR systems)

Two batch tests were conducted at the end of this run to evaluate the combined effects of cadmium and zinc shock loads on the sludge IV. First test was conducted for sludge collected from AS pilot plant (test IV for AS). Second test was conducted for sludge collected from SBR pilot plant (test IV for SBR). The efficiency of COD removal and the MT were measured under different doses of metals (cd/ zn doses: 0.0/0.0; 2.5/2.5; 5.0/5.0 and 10.0/10.0 mg l^{-1}). The summary of results of test IV is shown in table 5. The relation between MT and cd/zn dose is shown in fig. 9. The relation between cd/ zn dose and COD removal is shown in fig. 10.

Fig. 9 shows that the MT of batch test for the acclimated sludge of SBR is higher than the MT of the acclimated sludge of AS under cd/ zn dose of 2.5/2.5 mg l^{-1}. However, under cd/zn doses of 5.0/5.0 and 10.0/10.0 mg l^{-1}, the MT of batch test for the acclimated sludge of SBR is lower than the MT of the acclimated sludge of AS. For example, the MT was 0.21 for sludge IV of SBR and 0.37 for sludge IV of AS system.

Fig. 10 shows that the efficiency of COD removal for sludge IV of SBR system is higher than the efficiency of COD removal for the sludge IV of AS system under the same doses of cd/zn. For example, E = 86% for sludge IV of SBR, where E = 66% for sludge IV of IV AS, both under cd/zn dose 10.0/10.0 mg 1^{-1}.

3.4.3. Comparison between AS and SBR systems under gradual increase of Cd and Zn

For both AS and SBR systems, the relation between the efficiency of the COD removal and cd/zn doses was studied under steady state operation (run I, run, II run III and run IV) Fig. 11 shows the effect of gradually increasing of cadmium and zinc doses on the treatment process. It is clear from this figure that the COD removal efficiency decreased for both AS and SBR systems under the gradually increasing of cadmium and zinc metals. It is also clear that for all cases f steady state operation, the COD removal of SBR system is higher than of AS system.

3.4.4. Comparison between AS and SBR systems under cd and zn shock loads (batch tests)

The effects of cd/zn shock loads on MT in both AS and SBR were studied using batch tests. These tests were carried out on sludge collected from steady state pilots after the four runs of operation. Fig. 12 shows the effect of the highest cd/zn dose (10.0/10.0 mg l^{-1}) on MT of the four experimented sludge for both AS and SBR. For all cases the MT of AS was higher than SBR which confirms that SBR is more capable to receive shock loads of cd/zn (10.0/10.0 mg l^{-1}). It is also obvious that the acclimated sludges are more capable, than the normal sludge, to receive cd/zn shock loads. Also the more the dose of metal added to the pilot plant during steady state operation the lower the effect of metal shock loads (MT).

4. Conclusions

Based on the observations and the results obtained from this study the following points are concluded.

Table 5
The combined effect of cd/zn shock loads on sludge IV for AS and SBR (Test IV)

Parameter	Sludge from AS pilot plant				Sludge from SBR pilot plant			
	Reactor 1 (control) 0.0/0.0	Reactor 2 cd/zn 2.5/2.5	Reactor 3 cd/zn 5.0/5.0	Reactor 4 cd/zn 10.0/10.0	Reactor 1 (control) 0.0/0.0	Reactor 2 cd/zn 2.5/2.5	Reactor 3 cd/zn 5.0/5.0	Reactor 4 cd/zn 10.0/10.0
F/M d^{-1}	0.40	0.40	0.40	0.40	0.23	0.23	0.23	0.23
E %	87%	83%	74%	66%	91%	90%	90%	86%
SOUR d^{-1}	1.438	1.327	1.051	0.912	0.816	0.708	0.658	0.646
MT	0.00	0.08	0.27	0.37	0.00	0.13	0.19	0.21

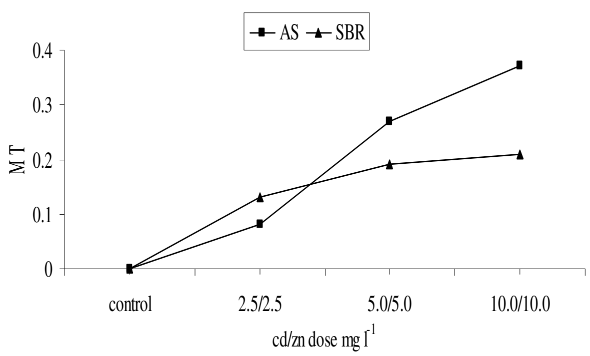

Fig. 9. Relation between MT and cd/zn dose (test IV).

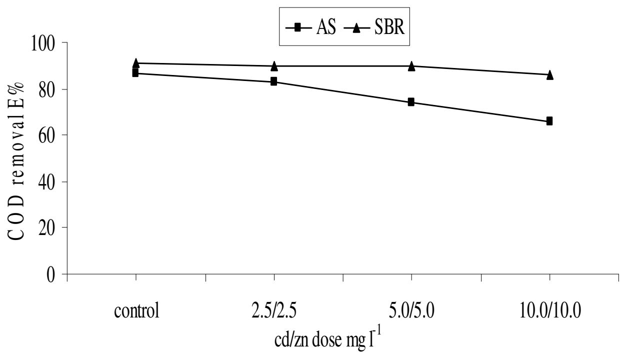

Fig. 10. Effect of cd/zn on the COD removal (test IV).

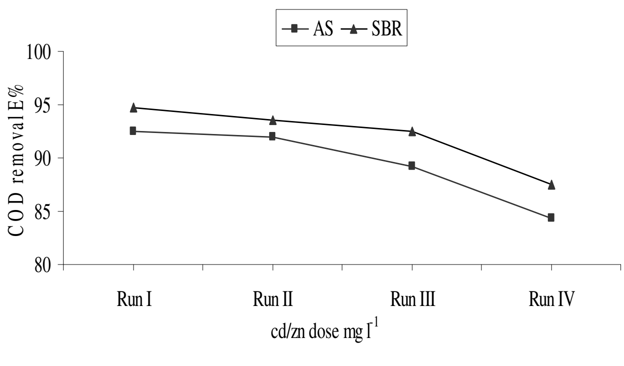

Fig. 11. Relation between COD removal and cd/zn dose (steady state).

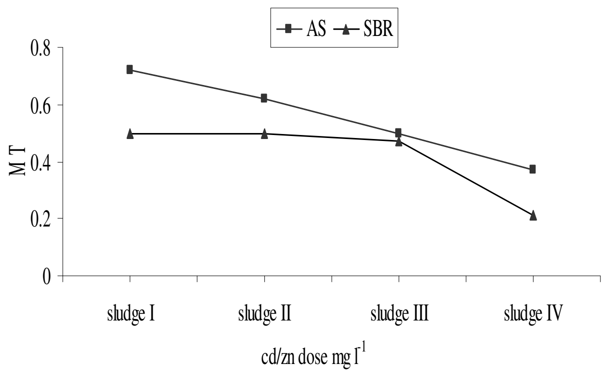

Fig. 12. Relation between MT and types of sludge under cd/zn dose 10.0/10.0 mg/l (batch tests).

1. The treatment efficiency (based on COD removal) decreases for both AS and SBR systems under the gradual increase of cadmium and zinc metals.
2. The COD removal of SBR system is higher than of AS system under steady state operation and the gradual increase of cadmium and zinc metals.
3. The acclimated sludge of both AS and SBR systems has a higher ability to receive the heavy metal shock loads than the normal sludge.
4. The treatment efficiency of both AS and SBR systems decreases under heavy metal shock loads. However the ability of sludge in the SBR system to acclimate with heavy metal shock loads is more than the sludge in AS system.
5. The MT of the acclimated sludge of SBR is lower than the MT of the acclimated sludge of AS under the same conditions.

Nomenclature

AS Activated sludge,
COD Chemical oxygen demand (mg l^{-1}),

COD_{in} Influent chemical oxygen demand (mg l^{-1}),
COD_{eff} Effluent chemical oxygen demand (mg l^{-1}),
E Efficiency of COD removal (%),
F/M Food to microorganisms ratio (d^{-1}),
MLSS Mixed liquor suspended solids (mg l^{-1}),
MT Metal toxicity,
OUR Oxygen uptake rate (mg l^{-1} hr^{-1}),
Q_{eff} Effluent flow rate (l d^{-1}),
Q_{in} Influent flow rate (l d^{-1}),
Q_R Return sludge discharge (l d^{-1}),
Q_W Waste sludge discharge (l d^{-1}),
SBR Sequencing batch reactor,
SOUR Specific oxygen uptake rate (d^{-1}),
T Temperature (C^o),
V_E Volumetric exchange ratio (%), and
θ_C Sludge age (d).

References

[1] E. F. Barth, M. G. Ettinger, B.V. Salotto, and G. N. McDermott, “Summary Report on the Effect of Heavy Metals on the Biological Treatment Processes,” J. WPCF, Vol. 37, pp. 86-96 (1965).

[2] E. Morgenroth and P. A. Wilderer, “Sequencing Batch Reactor Technology : Concepts, Design and Experiences,” J. CIWEM, Vol. 12 (1998).

[3] A. M. Sayed-Ahmed, Design and Operation of Sequencing Batch Biological Treatment Reactors, M.Sc. thesis, Sanitary Eng. Dept., Faculty of Eng., Alexandria University, Egypt (2000).

[4] T. G. Flapper, N. J. Ashbolt, A .T. Lee, and M. O’Neill, “From the Lab to Full-Scale SBR Operation: Treating High Strength and Variable Industrial Wastewaters”, Wat. Sci. Tech., Vol. 38, pp. 347-354 (2000).

[5] A. S. Weber and J. H. Sherrard, “Effects of Cadmium on the on the Completely Mixed Activated Sludge Process”, J. WPCF, Vol. 52, pp. 2378-2388 (1980).

[6] M. M. Bagby and J. H. Sherrard, “Combined Effect of Cadmium and Nickel on the Activated Sludge Process”, J. WPCF, Vol. 53, pp. 1609-1619 (1981).

[7] P. Battistoni, G. Fava and M. L. Ruello, “Heavy Metal Shock Load in Activated Sludge Uptake and Toxic Effects”, Wat. Res., Vol. 27 (1993).

[8] APHA, Standard of Methods for Examination of Water and Wastewater, 19th ed., American Public Health Association, Washington, D.C. (1995).

[9] M. Muniz, A. G. Lavin and M. Diaz, “Start-Up Strategy for SBR Treatment of Complex Industrial Wastewater”, Wat. Sci. Tech., Vol. 30 (1994).

[10] R. D. Neufeld and E. R. Hermann, “Heavy Metal Removal by Acclimated Activated Sludge”, J. WPCF, Vol. 47, pp. 310-329 (1975).

[11] H. P. Kaballo, “Shock Loading Management with the Sequencing Batch Biofilm Reactor Technology”, Wat. Sci. Tech., Vol. 35, pp. 35-40 (1997).

Received October 8, 2002
Accepted November 14, 2002