Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2020.26479

208 (2020) 136–147
December

Evaluation the performance of sequencing batch reactor and bio-film sequencing batch reactor for pulp and paper wastewater treatment

Shrouk Adel, W.A. Ibrahim, Mai Fayed*, Samia A. Aly

Sanitary Engineering Department, Faculty of Engineering, Alexandria University, Alexandria, Egypt, Tel. +2012-7322-4031; email: shk.adel@gmail.com (S. Adel), Tel. +201001679698; email: welbarki76@gmail.com (W.A. Ibrahim), Tel. +201202006111; email: mai.fayed@alexu.edu.eg (M. Fayed), Tel. +201273910407; email: samia.aly@alexu.edu.eg (S.A. Aly)

Received 5 November 2019; Accepted 23 August 2020

ABSTRACT

Pulp and paper industry produces effluents with harmful compounds that require appropriate treatment to improve its quality to meet the stringent discharge standards. This study aims to investigate the effect of operating conditions on the performance of two methods, bio-film sequencing batch reactors (SBR) and conventional SBR, used for pulp and paper wastewater treatment. Synthetic feed samples with a composition of chemical oxygen demand (COD) equals 2,500 mg/L were employed. Two identical reactors were operated in parallel for six separate scenarios. In the first three scenarios, the reactors were operated with different hydraulic retention times (HRT) of 2, 3, and 4 d, respectively. The fourth and fifth scenarios had HRT of 4 and 3 d under specific concentrations of lead and zinc (2 and 3.6 mg/L, respectively). The sixth scenario was operated under shock loads of lead and zinc (4 and 7.2 mg/L, respectively) at hydraulic retention time of 3 d. On the other side, general purpose simulator was applied to investigate the performance of SBR and bio-film SBR under various organic and hydraulic loads. Also, the performance of the two reactors under shock organic loads (COD reaching up to 5,000 mg/L) was investigated. Experimental results indicated that bio-film SBR provided better performance than SBR and had a high ability to sustain the various organic hydraulic loads of pulp and paper wastewater. The results recorded that average COD removal efficiency for the SBR and bio-film SBR systems were 97.0% and 99.21%, respectively. Simulation results showed that bio-film SBR outperform SBR treatment under different organic and hydraulic shock loads.

Keywords: Sequencing batch reactor; Pulp and paper; Wastewater treatment; Activated sludge model; General purpose simulator

1. Introduction

The pulp and paper industry is one of the rapidly growing industries in the world. In 1998, Egypt's pulp and paper products amounted to 314 thousand tons. It is one of the notorious polluters of the environment when discharged to water streams [1]. The main problem resulted from the pulp and paper industry is the disposal of tremendous volumes of wastewater. This wastewater is rich in dissolved solids such as chlorides and sodium and calcium sulfates, varying amounts of suspended organic materials, chemical, or biological oxygen demand, and color causing compounds [2]. In addition to these constituents, effluents also contain some trace metals like Hg, Pb, Zn, Cr, and others [3]. Pulp and paper mill wastewater treatment is of immense concern for the environment due to its after-effects. Several studies for the treatment of pulp and paper wastewater were carried out by using physicochemical treatment methods. Being energy-intensive and more expensive these methods were not implemented at industrial sites. Researchers are now more focused on using biological treatment process for the treatment of pulp and paper wastewater because physical

* Corresponding author.

and chemical processes are not capable of removing biological oxygen demand (BOD) and low molecular weight compounds [1].

The SBR is known as a flexible and effective system for the biological treatment of wastewater, even though with high concentrations of toxic compounds produced by various industrial processes. Due to its operational flexibility, it is quite simple to increase the efficiency in treating wastewater by changing the duration of each phase rather than adding or removing tanks in continuous flow systems [4]. Sequencing batch reactors (SBR) are widely used for industrial wastewater treatment. It is the only commonly applied activated sludge variant that is designed to operate in a cyclic or intermittent mode. The differences between treatment trains incorporating the continuous flow activated sludge processes and the SBR begin from the aeration vessel onwards. Typically, the continuous flow activated sludge process operates with aeration vessels and secondary clarifiers. There would be sludge return from the secondary clarifier to the aeration vessel. The SBR operates without the secondary clarifier and is therefore devoid of the sludge return from the latter. The SBR system however has some disadvantages such as the high excess sludge produced and the high sludge volume index [5].

The SBR is a single-tank fill-and-draw unit that utilizes the same tank to aerate, settle, and withdraw effluent [6]. Once the tank is filled, the wastewater is mixed without aeration to allow the metabolism of the fermentable compounds. The next step is the aeration step, which enhances the oxidation and the formation of biomass. Sludge is settled afterward and the treated effluent is removed to complete the cycle. The SBR depends mainly on the site operator to adjust the duration of each phase to reflect fluctuations in wastewater composition. It is reported that the SBR is a cost-effective primary and secondary treatment option to handle pulp and paper plant wastewater [4]. The efficiency of SBR can be improved using suspended media [7]. In this regard, extensive research has been performed in relation to processes which employ adhered biomass, since these have some advantages over conventional processes such as high biomass concentrations can be attained which eliminates the need to re-circulate the sludge and ensures a greater value of sludge age; absence of risk of biomass leaching since with the biomass adhered to the support the reactor can operate at flow rates independently of the maximum specific growth rate; and lower hydraulic retention time can be employed to achieve the same efficiency [8].

Ranjith Kumar and Subramanian [4] conducted laboratory experiments using an SBR at different operating conditions, including mixed volumetric exchange rate, aeration time, temperature, and daily operation cycle as a biological treatment of the pulp and paper mill effluent. In this study, the performance of the SBR with respect to effluent quality was satisfactory under various operational conditions. Under optimal aeration conditions, the effect of hydraulic retention times (HRT) and volumetric organic loading rate effectively enhanced the removal efficiency. The effluent which had a high organic strength at the initial stage was efficiently reduced. Common problems like sludge bulking were almost absent. The study investigated the treatment of pulp and paper wastewater using SBR. Experimental work included studying the effect of aeration time, retention time, and organic loadings on removal efficiencies. However, this work did not include the impact of heavy metals on the removal efficiencies nor the effect of shock loads. Also, a comparison between the performance of SBR and bio-film sequencing batch reactors (BSBR) was not provided.

Husain et al. [9] investigated the treatment of wastewater samples taken from a pulp and paper mill factory in Moradabad, India with different batch characteristics using BSBR which operated in an aerobic condition in order. The removal of chemical oxygen demand (COD) was found to be decreased with the decreasing of the HRT. The efficiency of a system is also very dependent on the characteristics of the microbe population in the reactor. The results showed that the microorganisms in the SBR system can remove both organic matters (COD and biochemical oxygen demand (BOD)) and color substances from the pulp and paper industry wastewater. The study investigated the reduction of COD of pulp and paper mill effluent using SBR. Experimental work included studying the effect of retention time and mixed liquor suspended solids (MLSS) concentrations on the removal efficiencies. But this study did not include the impact of heavy metals on the removal efficiencies or the effect of shock loads. The effect of suspended media was investigated; however, it was not compared with conventional SBR.

Verma et al. [10] studied the biosorption of lead and zinc from pulp and paper industry effluent by water hyacinth (*Eichhornia crassipes*). Pulp and paper industry effluent contains 1.30 and 1.39 ppm for Zn and Pb, respectively. The results showed that the metal uptake by water hyacinth was higher at a low effluent concentration (up to 20%) and decreased thereafter with the increase in effluent concentration due to the toxicity at higher effluent concentration. Metal reduction of Pb and Zn was almost the same up to 15 d of treatment but afterward reduction of Zn declined as compared to that of Pb. Maximum reduction (73.4% for Zn, 80.3% for Pb) in metal content was found in 20% effluent concentration after 20 d of treatment. The low concentrations of Zn in the effluent supported the plant growth and metabolism and led to increase plant uptake. This study reveals that water hyacinth has a strong potential to uptake the toxic heavy metals from pulp and paper industrial wastewater and hence biological treatment may turn out be a viable option.

In 1983, the International Water Association (IWA) formed a task group mainly to develop a model for the design and operation of the biological wastewater treatment process. The outcome of the group's work is activated sludge model no. 1 (ASM 1) [11]. In later years, the association introduced other versions that expanded and improved upon the first model. The association included activated sludge model no. 2 (ASM 2) [12], which includes phosphorus removal from wastewaters. Activated sludge model no. 2, which takes into account, the ability of phosphorus-accumulating organisms to use cell internal substrates for denitrification. The association also developed activated sludge model no. 3 (ASM 3) [13], which does not include phosphorus removal but targets problems found in the first model.

General purposes simulator (GPS-X) is a unit, multipurpose modeling environment for the simulation of domestic and industrial wastewater treatment plant (WWTPs). It is the world's premier WWTP simulator. GPS-X uses a sophisticated graphical user interface to simplify dynamic modeling and simulation for users; there is no other software for modeling and simulation of wastewater treatment processes which is equipped with similar power and flexibility obtainable with GPS-X. It is state-of-the-art technology, using the most recent advances in process modeling, simulation technology, graphics, and a host of productivity tools that simplify model construction, simulation, and interpretation of results. The ASM1 model was used for biological processes, and the BOD-based influent model was applied for influent characterization. Default values for all kinetic and stoichiometric parameters in the ASM1 model were used for the simulations [14].

The aim of the current study is to evaluate the efficiency of SBR and BSBR treating pulp and paper wastewater. On one side, the comparison includes the effect of different HRT as an operation condition; and on the other side, the effects of zinc and lead concentrations and shock loads in treatment performance have been investigated. Also, the modular program GPS-X v5.0 was used to predict the performance of BSBR and SBR at different scenarios that include the impact of hydraulic and organic shock loads.

2. Materials and methods

2.1. Synthetic wastewater

The influent wastewater employed in the two reactors is synthetic wastewater. Synthetic wastewater that has been used is similar to the effluent of the pulping phase that it had been characterized to contain very high COD and TSS [15]. The synthetic feed compositions are 2,500 mg/L as COD [16], 125 mg/L for NH_3–N, and 1.75 mg/L for NO_3–N. The synthetic samples were prepared by diluting with tap water (1:100). A concentrated stock solution containing 243 g/L glucose monohydrate (99% – manufactured by leading worldwide chemicals companies), 58.25 g/L sodium thiosulphate-5-hydrate (99% – manufacturer ALPHA CHEMIKA), and 44 g/L ammonium sulfate (98.5% – manufacturer El Nasr Pharmaceutical Chemicals Company), was used to prepare the daily synthetic influent [17].

2.2. Pilot – scale bioreactor

The system used in this work consists of two parallel reactors as shown in Fig. 1. The two reactors made of Perspex had the same dimensions (length = 30 cm, width = 20 cm, depth = 35 cm, depth of water = 25 cm, working volume = 15 L). The first reactor was operated as conventional SBR while the second one was operated as BSBR by adding suspended plastic media. The operation cycle stages are shown in Fig. 2. Cycle length was 24 h (1 cycle/d). The sludge retention time (SRT) is 10 d for SBR and 15 d for BSBR to decrease the total amount of excess sludge. Properties of plastic balls that are used as suspended media are shown in Table 1.

2.3. Experimental procedures

The two reactors were operated in parallel for six separate scenarios as shown in Fig. 3. In the first three scenarios, HRT was changed to be 2, 3, and 4 d respectively, with zero concentration of Pb and Zn. In the fourth and fifth scenarios, Pb concentration equals 2 mg/L and Zn concentration equals 3.6 mg/L, two HRT were used for 4 and 3 d, respectively [18]. The sixth scenario operated with both zinc and lead shock loads of 7.2 and 4 mg/L, respectively at HRT equaling 3 d.

2.4. Analytical procedures

COD, dissolved oxygen (DO), nitrogen ammonia (NH_3–N), nitrate (NO_3–N), mixed-liquor suspended solids (MLSS), lead (Pb), and zinc (Zn) are observed and the data recorded each time by methods provided at Standard Methods for the examination of water and wastewater [19].

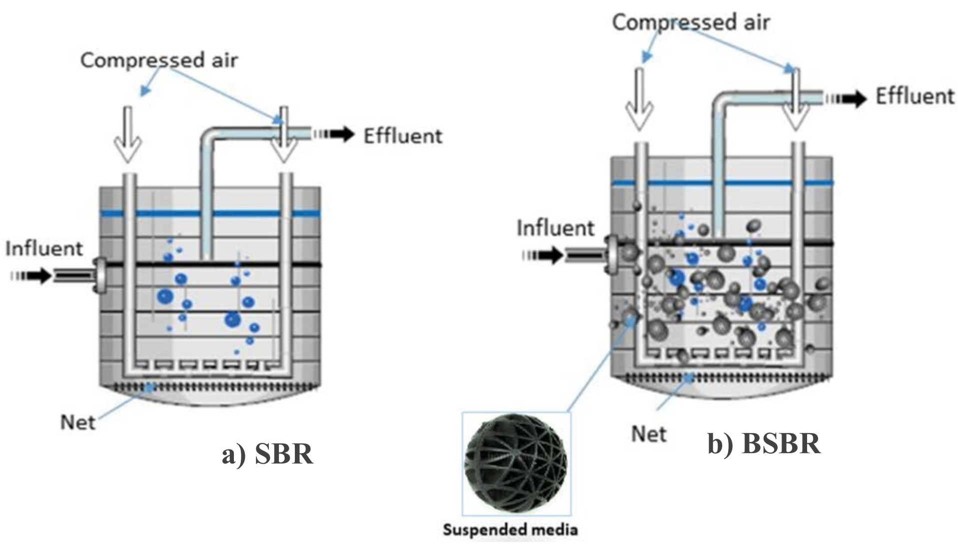

Fig. 1. Experimental tanks of (a) SBR and (b) BSBR.

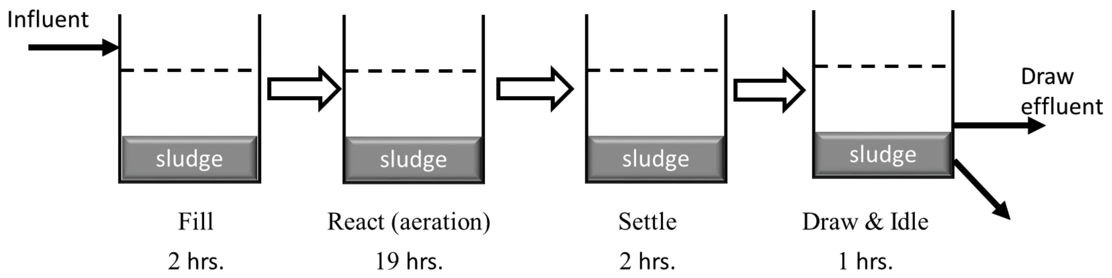

Fig. 2. Typical operation sequence.

Table 1
Properties of the plastic ball: "bio-balls" from ornamental fish shops

Properties	Value
Diameter/ball	5 cm
Volume/ball	65.44 cm^3
Net volume/ball	45.55 cm^3
Surface area/ball	219.8 cm^2
Weight/ball	12.5 g
Density/ball	0.191 g/cm^3
Number of balls in reactor	10 balls
Total surface area of balls	0.2198 m^2
Total net volume of media in reactor	455.5 cm^3
Percentage of media gross volume/reactor volume	4%
Total weight of media in reactor	125 g

The COD is determined using the colorimetric method by spectrophotometer (DR2010 Colorimeter Hach, USA). The DO was measured using the electrometric method with the oximeter for oxygen (YSI model 57 Oxygen Meter Yellow Spring In., Co., USA). Metals (magnesium, calcium, sodium, and potassium) and heavy metals (lead, zinc, copper, iron, chromium, nickel, manganese, cobalt, and cadmium) were determined in samples by atomic absorption spectrophotometer Shimadzu Model (AA-6650). Samples were taken frequently from influent feed and effluent of each reactor.

2.5. Statistical analyses of the data

The given graphs were constructed using Microsoft excel software. Descriptive statistics including the mean, median with standard deviation, and standard error, were used to compare different scenarios of operations; while percent was used to describe the categorical data. The percent of COD removal or reduction was calculated using the Eq. (1):

$$\% \text{ Removal} = \left(\frac{\text{COD}_i - \text{COD}_f}{\text{COD}_i}\right) \times 100\% \quad (1)$$

where COD_i is the initial concentration (ppm); COD_f is the final concentration (ppm).

3. Results and discussion

3.1. Hydraulic retention time (HRT) impact on effluent characteristics

In this section, the impact of HRT on the reduction of COD, NO_3–N, NH_3–N, and solids removal was evaluated. During this experiment, the two reactors (SBR and BSBR) were operated in parallel using three different HRT (2, 3, and 4 d) without any addition of Pb and Zn. In each experiment, the reactors were operated till reaching steady-state conditions, and afterward, samples were taken each day up to the 12th day. Figs. 4 and 5 present the impact of HRT on COD removal and COD concentrations in the effluent for the SBR and BSBR reactors, respectively. The results showed that increasing HRT improves the removal of COD for both reactors (SBR and BSBR). For the SBR reactor, the removal efficiency of COD is enhanced from around 89% (HRT = 2 d) to around 97% (HRT = 4 d). The concentration of COD in the effluent water was around 270 mg/L at HRT equals 2 d while it was almost 70 mg/L at HRT equals 4 d. Increasing HRT from 2 to 4 d enhances the contact time between organic compounds and microorganisms which provides a better decomposition of the organic compounds [20]. The same results were obtained by Afzal Husain et al. [9], where COD removal efficiencies of the SBR system were increased from 73% to 89% when HRT of the system was increased from 1 to 3 d. Also, Khan et al. [20] reported an improvement in the removal efficiency of COD when time increased from 8 to 24 h [20]. On the other hand, Ranjith Kumar and Subramanian [4] conducted a study to investigate the SBR performance in pulp and paper wastewater treatment and observed that COD removal efficiency for the SBR system was 80% when the retention time was varied from 8 to 24 h.

In the case of the BSBR reactor, the removal efficiency of COD is enhanced from around 94% (HRT = 2 d) to around 99% (HRT = 4 d). The concentration of COD in the effluent water was around 150 mg/L at HRT equals 2 d while it was almost 40 mg/L at HRT equals 4 d. This data demonstrated that the performance of BSBR is better than the conventional SBR in reducing organic materials measured as COD. The better removal of COD obtained by BSBR is attributed to the addition of bio-balls which enhance the

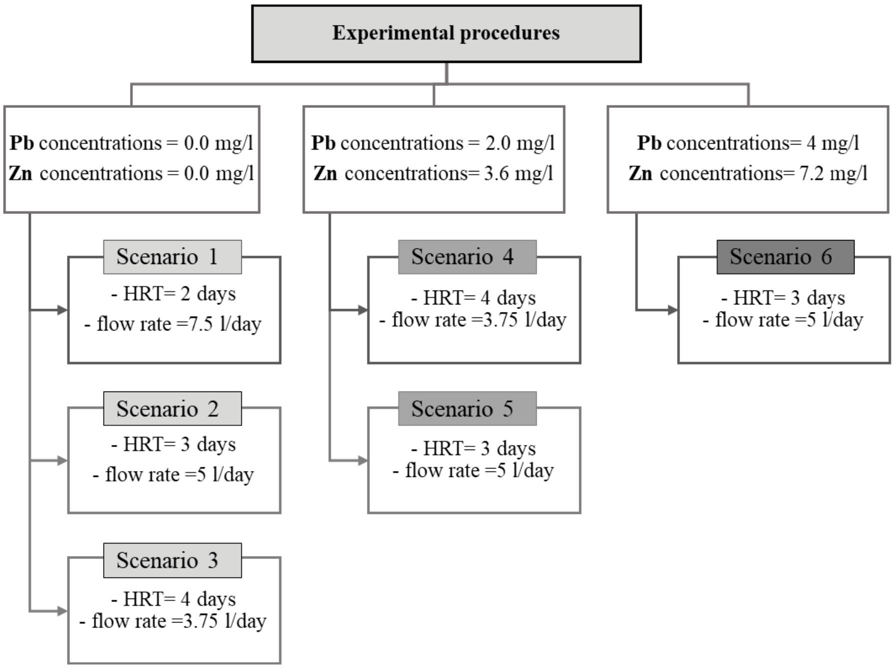

Fig. 3. Experimental procedures.

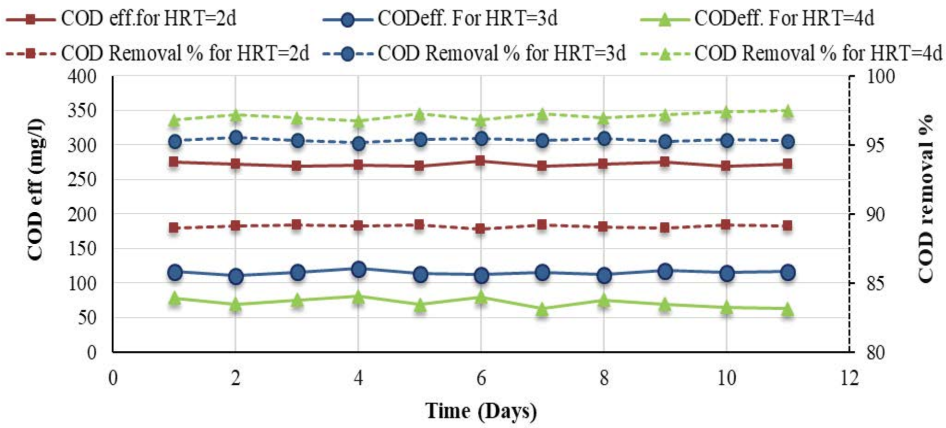

Fig. 4. Effluent COD and removal efficiency at different HRTs for SBR.

oxidation process due to a higher population of attached microorganisms [20].

Fig. 6 provides the concentration of MLSS during the experiment time (around 11 d) for the two rectors (SBR and BSBR) under the investigated HRT (2, 3, and 4 d). It can be noted from the figure that the value of MLSS was reduced with increasing HRT for the two reactors. Further, the increase in the settling period enhanced the efficient reduction of solids concentration. BSBR reactor provides a higher reduction in solids than that by SBR. This may be attributed to the heavy and dense biofilm attached to bio-balls used in the BSBR system [21].

One of the main objectives of wastewater treatment is reducing the possible nutrients such as nitrogen which have an adverse impact on water streams and cause eutrophication [22]. Organic nitrogen primarily is present in wastewater as ammonia that can be converted into nitrite, and nitrite into nitrate, by the nitrifying bacteria as nitrification process [22]. The performance of the two systems (SBR and BSBR) in reducing nitrate and ammonia was investigated and the results are shown in Figs. 7 and 8, respectively. The results showed that increasing HRT led to a decreasing trend in effluent NO_3–N because the increase of HRT allows the wastewater to remain longer in the reactor which allows great opportunities for biological reactions and raises the possibility of microorganisms to gather with each other. Fig. 8 showed that the increase in HRT led to an increasing trend in NH_3–N removal efficiency. This may attributed to the enhancement of the nitrification bacteria population due to HRT increase. It can be also noted from the figure that the

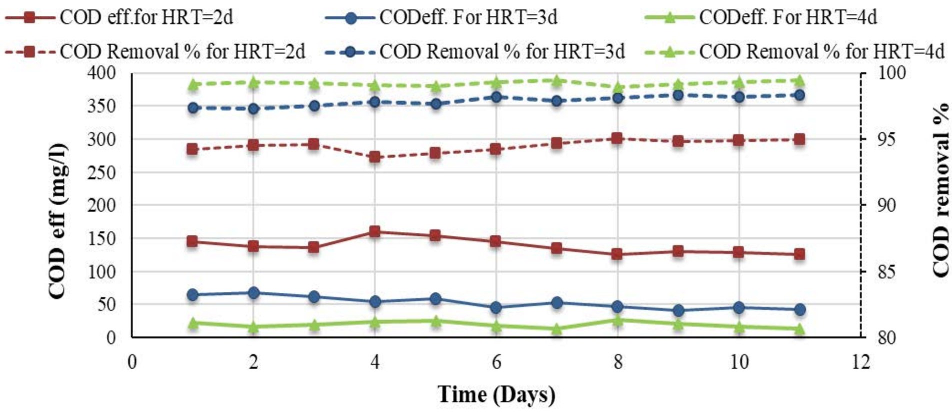

Fig. 5. Effluent COD and removal efficiency for different HRTs for BSBR.

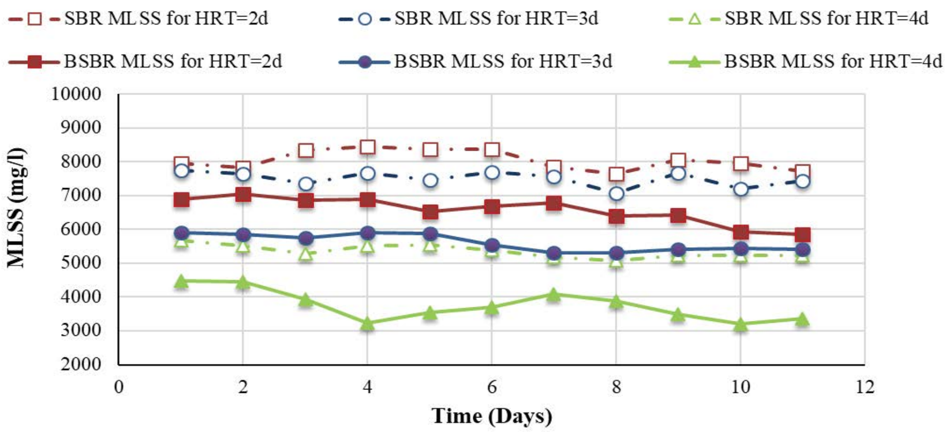

Fig. 6. MLSS (mg/L) for SBR and BSBR for different HRTs.

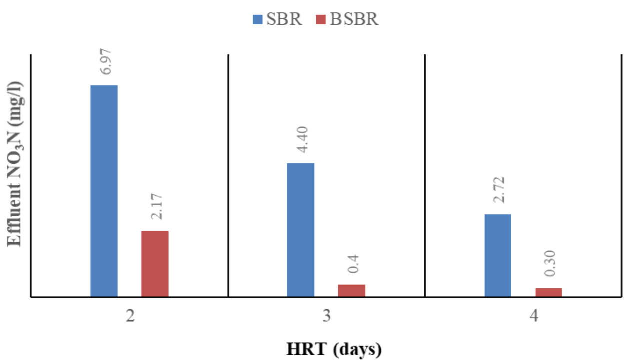

Fig. 7. Effluent NO_3–N (mg/L) for SBR and BSBR for different HRTs.

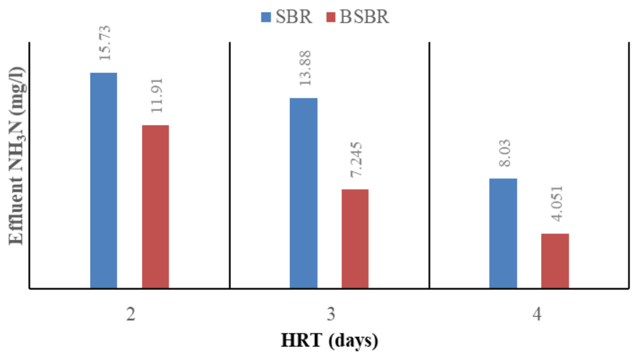

Fig. 8. Effluent NH_3–N (mg/L) for SBR and BSBR for different HRTs.

NH_3–N removal efficiencies in BSBR are higher than that of conventional SBR because of the large surface area of media that works on microorganisms gathering and enhances the bacterial activity.

The results of the first scenario suggest that the effluent quality is better when HRTs are 3 and 4 d and hence, those HRTs were chosen for the following scenario.

3.2. Impact of adding lead(Pb) and zinc(Zn) on the effluent characteristics

Most pulp and paper wastewater contains some heavy metals which may impact the biodegradation process [23]. In this section, the effect of adding lead and zinc with doses equal to 2.0 and 3.6 mg/L, respectively, on COD removal by

SBR and BSBR was investigated. Fig. 9 presents the removal efficiency of COD for the SBR reactor when lead and zinc were added to the feed wastewater. Fig. 10 presents the removal efficiency of COD for BSBR reactor when lead and zinc were added to the feed wastewater. The results show that adding lead and zinc to the feed wastewater causes a decrease in COD removal efficiency for the two reactors (when data compared with those obtained during the previous scenario). However, increasing HRT from 3 to 4 d provides an enhancement in the removal efficiency of COD for the two reactors.

The performance of the two reactors (SBR and BSBR) in the removal of lead and zinc was also studied and data is presented in Figs. 11 and 12. It can be noticed from Fig. 11 that both reactors have an ability to reduce lead from feed water and increasing HRT provides better reduction. It also can be noted that the effluent value of lead for the two reactors is almost the same (e.g., at HRT equals 3 d, the effluent value of a lead is 1.36 and 1.3 mg/L for SBR and BSBR, respectively). The same trend occurred in the two reactors for zinc removal as shown in Fig. 12. The two reactors (SBR and BSBR) are able to reduce zinc from feed wastewater and increasing HRT provides some enhancement in the removal. Lead and zinc can be removed by microorganisms and biological absorption on the biomass surface that settled in the reactor [10].

3.3. Effect of shock loads (Pb/Zn dose 4/7.2 mg/L) on the effluent

The effect of shock loads of lead and zinc concentrations on the removal of COD by the two reactors was investigated under one HRT equals 3 d. Fig. 13 shows the performance of the two reactors (SBR and BSBR) in reducing COD when higher concentrations of lead and zinc were applied. The results showed that the COD removal efficiency decreased significantly under heavy metals shock loads. The COD concentration in effluent treated wastewater reached 400 mg/L at the end of the experiment time (12 d of operation) for the SBR, while it is around 200 mg/L for the BSBR. Conventional SBR showed higher DO consumptions compared to that of BSBR (data not provided here). Results showed a residual DO of 1.66 mg/L for SBR at HRT of 3 d, and 4.76 mg/L for BSBR under the same organic shock loads (more details may be found at Hassan [24]). Fig. 14 shows the effluent concentrations of lead and zinc for the two reactors (SBR and BSBR). It can be noticed that lead and zinc removal efficiencies decreased under shock loads; however, the system maintained its stability.

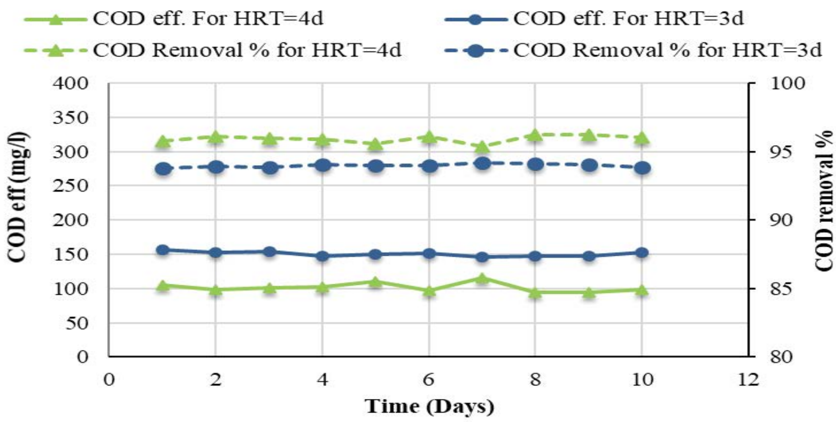

Fig. 9. Effluent COD and removal efficiency for different HRTs for SBR under Pb/Zn dose 2/3.6 mg/L.

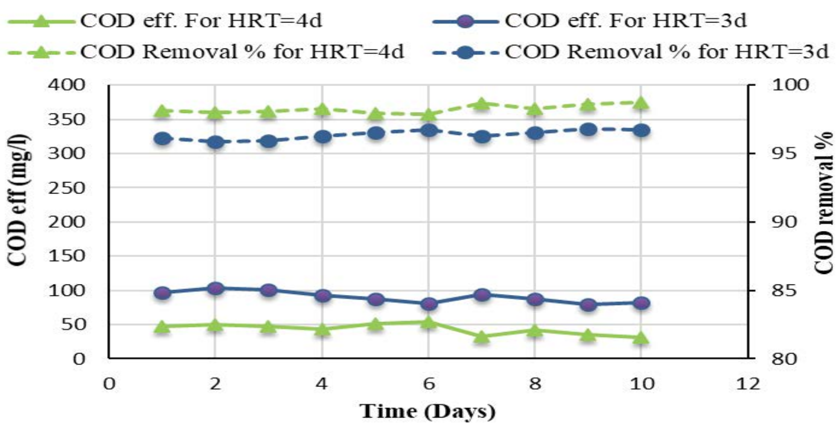

Fig. 10. Effluent COD and removal efficiency for different HRTs for BSBR under Pb/Zn dose 2/3.6 mg/L.

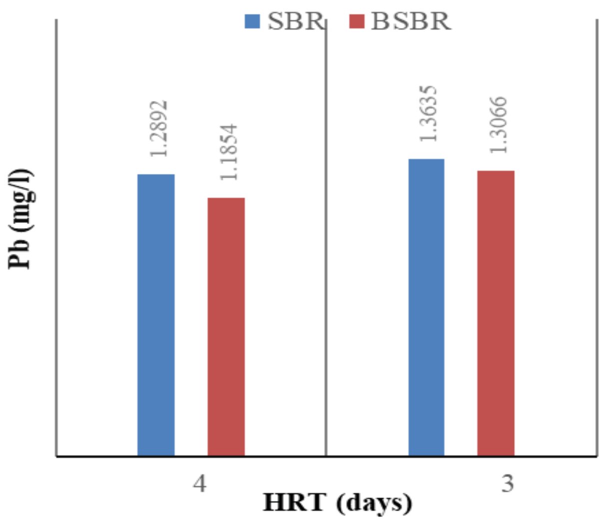

Fig. 11. Effluent Pb (mg/L) for SBR and BSBR for different HRTs.

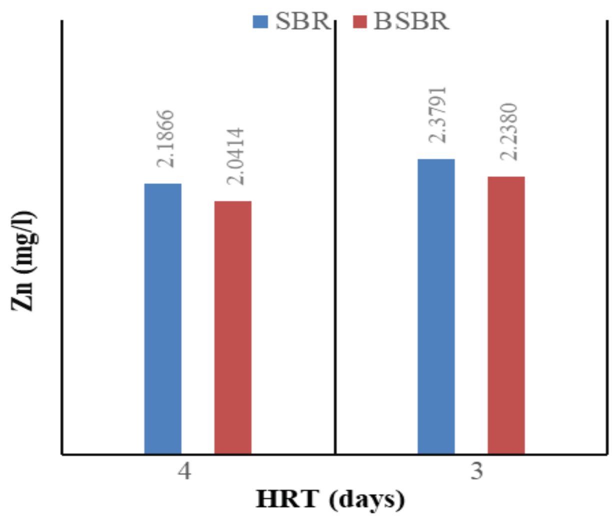

Fig. 12. Effluent Zn (mg/L) for SBR and BSBR for different HRTs.

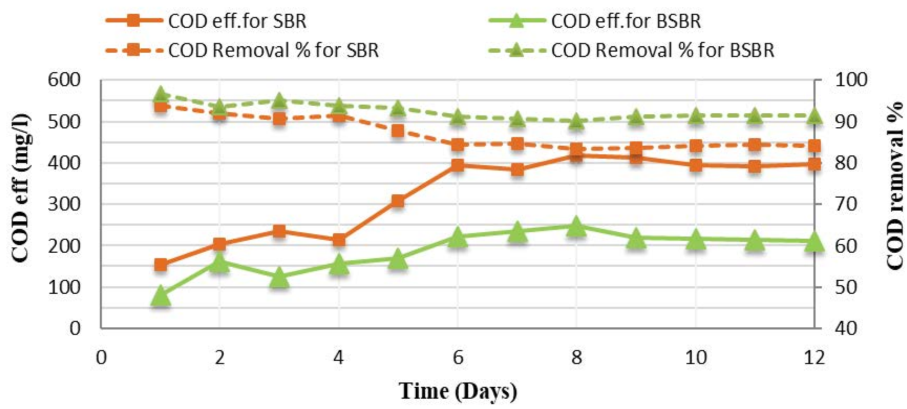

Fig. 13. Effluent COD and removal efficiency for SBR and BSBR under organic shock loads.

4. Modeling and simulations

4.1. Plant configuration and operation conditions

Simulations were performed for the two reactors (SBR and BSBR) using modular program GPS-X. HRT was selected to be 4 d, as it was the one that provides higher performance for the two reactors as obtained from the experimental work, and the entire run lasts for 13 d. The influent wastewater for both SBR and BSBR plant models contains a BOD_5 of 1,750 mg/L and a TKN of 93.3 mg/L. The operation conditions of the SBR and BSBR plant were as follows:

- SBR tank working volume = 15 L, total SBR tank volume = 21 L.
- Area of SBR tank = 600 cm^2, total SBR tank depth = 35 cm.
- Average influent flow rate = 3.75 L/d.
- Total cycle time = 24 h (1 cycle/d).
- Total fill time = 6 h (3 h mixed fill, and 3 h aerated fill).
- Aeration time = 9 h.
- Settling time = 3.67 h, decant time = 4 h. Waste sludge time = 1.33 h.

4.2. Activated sludge model No. 1 (ASM1)

The International Association of Water Pollution Research and Control (IAWPRC) task group realized that, because the solids retention times are long and the bacteria have low growth rates, the actual effluent substrate concentrations between different activated sludge treatment plants did not vary greatly. What was significantly different were the levels of MLSS and an electron acceptor (oxygen or nitrate). Thus, the focus of the Activated Sludge Model No. 1 (called ASM 1 in GPS-X) is to predict the amount and variation of the solids and electron acceptor.

In the development of activated sludge modeling, how the quantity of organic matter is measured (BOD, COD) is inconsistent. The task group decided to use COD since mass balances can be carried out and since it has links to the electron equivalents in the organic substrate, biomass, and electron acceptor.

The organic material is categorized according to a number of characteristics. First is the biodegradability of the material. The non-biodegradable organics pass through the system unchanged and can be further categorized according to their physical state (soluble or particulate), which is removed from the system by different pathways. The particulate material is generally removed with the waste activated sludge, while the soluble material is removed with the effluent. The biodegradable material is categorized as either readily or slowly biodegradable. The task group treated the former as soluble material, while the latter was treated as particulate material (this is not strictly correct, but simplifies matters). The readily biodegradable organics may be utilized for cell maintenance or growth with a transfer of electrons to the acceptors. The particulate (slowly) biodegradable substrate is hydrolyzed to readily biodegradable material, assuming no energy utilization, and no corresponding use of electron acceptor. All scenarios simulated in this work utilized the above mentioned ASM 1 model developed by IAWPRC task group.

4.3. Model validation

Model validation aims to assure the compatibility between the results obtained in the laboratory to those calculated from the model for BOD, COD, TSS, and TKN. The effluent's actual results from the laboratory were compared to the modeled effluent results for COD, BOD, and TSS and it was noted that the simulation results showed good agreement with the actual results from the laboratory as shown in Fig. 15 by 4% error percentage for SBR and 5.5% for BSBR.

4.4. Modeling scenarios

After the model was validated, simulations were conducted under different conditions to predict the performance of SBR and BSBR under these conditions. These different scenarios and their simulation results are discussed in detail in the following sections.

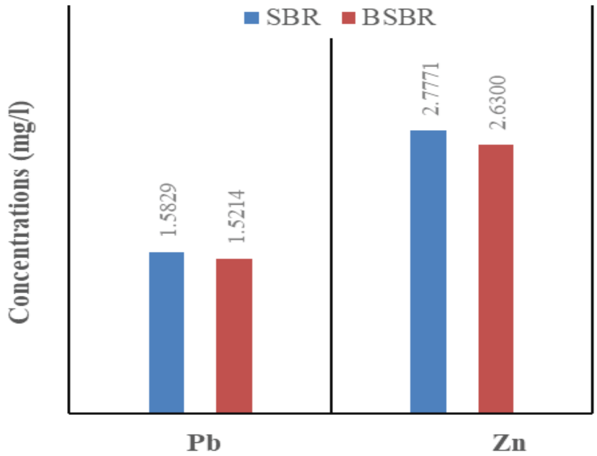

Fig. 14. Effluent Pb and Zn (mg/L) for SBR and BSBR under organic shock loads.

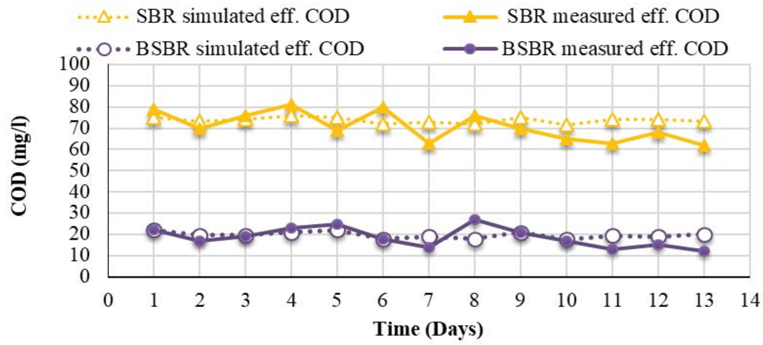

Fig. 15. Simulated effluent COD and measured effluent COD for both SBR and BSBR.

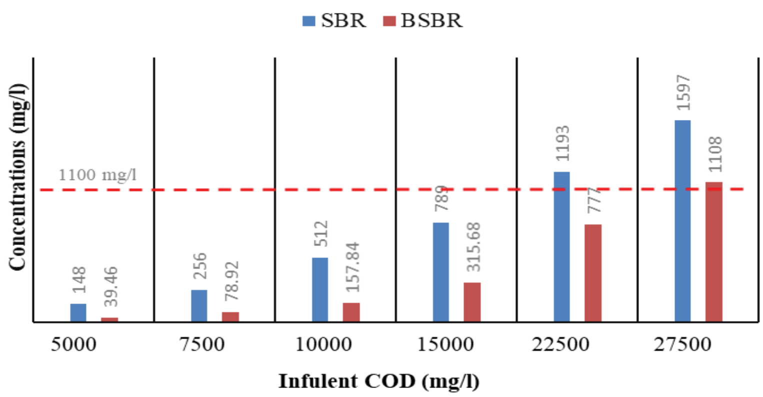

Fig. 16. Effluent COD for both SBR and BSBR under different organic loads.

4.4.1. Scenario 1: organic loads impact on reactors performance (changing influent concentrations of COD)

Previous studies reported that pulp and paper wastewater contains a heavy concentration of COD [2]. Hence, in this scenario, the impact of influent concentrations of COD on the performance of SBR and BSBR was investigated. Six different COD values were investigated 5,000; 7,500; 10,000; 15,000; 22,500; and 27,500 mg/L. Fig. 16 shows the simulation results for this scenario. Results showed that effluent COD concentrations increased when the organic load increased. However, it was noticed that BSBR had a higher ability to sustain high organic loads than that by SBR. It can be also noticed that at maximum concentrations, BSBR was able to treat wastewater with accepted values, unlike that of SBR. The efficiency of the SBR system degraded at an influent concentration of COD equals 22,500 mg/L and the effluent value of COD reaches 1,193 mg/L which was out of the permissible limits. The permissible limit was 1,100 mg/L to divert to the sewage system according to the Egyptian environmental law (Law no 44/2000), on the other hand, BSBR maintained its stability at the same value of COD and the treated effluent was within the permissible limits. BSBR's removal efficiency started to degrade and exceed the permissible limits at COD of 27,500 mg/L.

4.4.2. Scenario 2: changing HRT by changing influent discharge

In this scenario, four different HRTs were investigated; 5, 6, 7, and 8 d as shown in Fig. 17. As expected and proved from laboratory data, results showed that increasing HRT enhanced the performance of both SBR and BSBR and COD removal though BSBR has performed better than SBR. This improvement in the two reactors performance may be attributed to the higher contact between the microorganisms and organic which provides better removal of influent COD [20].

4.4.3. Scenario 3: organic shock load

In this scenario, simulations were conducted under the same influent COD (2,500 mg/L), but in the presence of an organic shock load. The main target of this scenario is to study the performance of the two reactors (SBR and BSBR) at any change of influent COD and how they can sustain their performance. This was achieved by increasing COD to 5,000 mg/L in the 3rd day and then returning it back to its original value of 2,500 mg/L in the following days as shown in Fig. 18. Fig. 19 represents the effluent concentrations of COD during the run time (13 d) for the two reactors. It can be noticed that the main effect of organic shock load was significant after the addition of high concentration of COD and a sudden increase in effluent COD was observed for both SBR and BSBR. However, it was noticed that BSBR recovered its stability after 7 d while SBR took 9 d to recover its stability. It was reported that biofilms can sustain more toxic and organics loads [21] which may interpret the better ability of BSBR to sustain organic shock loads.

4.4.4. Scenario 4: hydraulic shock load

In this scenario, simulations were conducted under the same discharge (3.75 L/d, HRT = 3 d). However, the discharge was doubled in the 3rd day only. This was achieved by decreasing the HRT to 2 d. The volume of reactors was large enough to accommodate double the discharge. Fig. 20 presents the effluent COD with time for the two reactors during hydraulic shock load. Results showed that the hydraulic shock load leads to an increase in effluent COD for both SBR and BSBR. It can be noticed that BSBR recovered its stability after 4 d while SBR took 5 d to recover. It was concluded that BSBR has a higher ability to sustain hydraulic shock loads than SBR.

5. Conclusion

SBR process has proven to be flexible and provides high-performance treatment technology for wastewater treatment, especially for pulp and paper wastewater. However, provide some modifications to SBR such as addition of bio-media (BSBR) may improve its performance. The purpose of this study was to evaluate the efficiency of using suspended media in BSBR systems in comparison with the conventional SBR for treating pulp and paper wastewater. Based on the results obtained from this study, it can be noted that BSBR showed higher COD and NH_3–N removal efficiencies compared to conventional SBR and COD removal efficiency reached 99% by BSBR at HRT of 4 d. In addition increasing, HRT enhanced the performance of both SBR and BSBR.

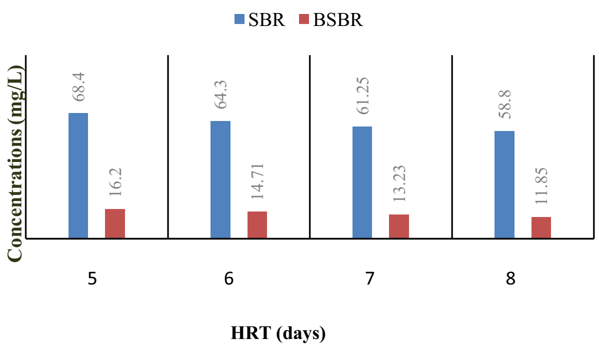

Fig. 17. Effluent COD for both SBR and BSBR at different HRTs.

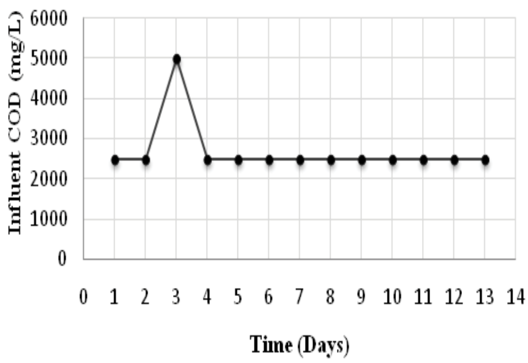

Fig. 18. Influent COD for both SBR and BSBR under organic shock load (COD = 5,000 mg/L).

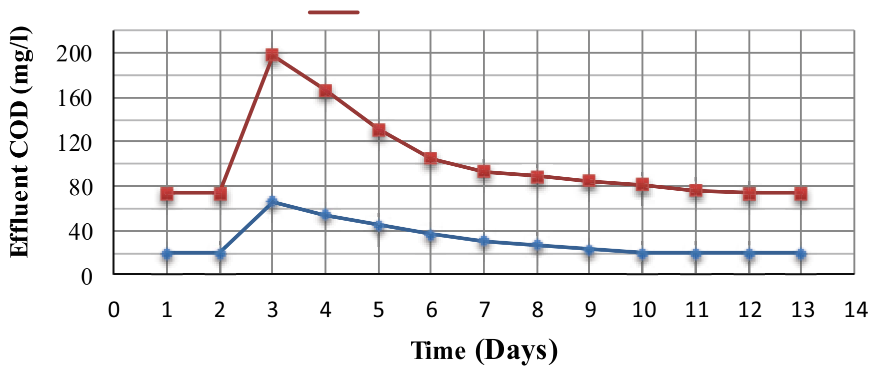

Fig. 19. Effluent COD for both SBR and BSBR under organic shock load (COD = 5,000 mg/L).

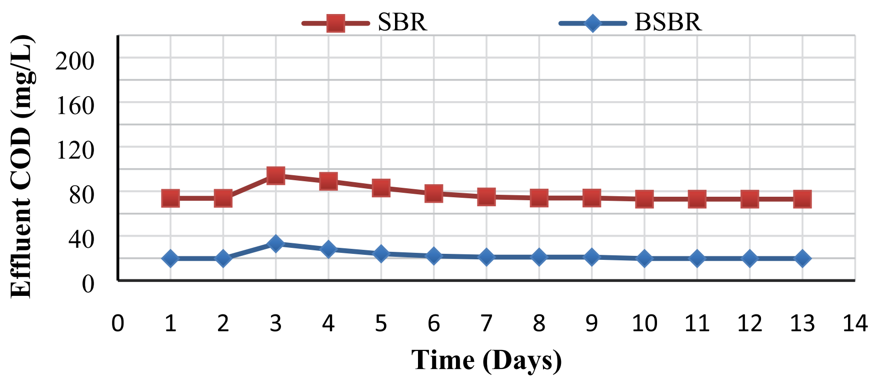

Fig. 20. Effluent COD for both SBR and BSBR under hydraulic shock load (2Q).

There was a large variation in COD values in case of adding lead and zinc concentrations. Results showed that SBR systems are not efficient to remove lead (Pub) and zinc (Zn) and additional treatment may be required to achieve good removal efficiencies. When lead and zinc shock loads are applied, the removal efficiencies of COD, Pb, and Zn reduced significantly; however, the system maintained its stability and BSBR showed better performance than SBR under different conditions.

Moreover, GPS-X model simulation showed a good agreement with the measured data for both SBR and BSBR reactors. Simulation results were a little higher than measured results according to the optimum operational conditions considered in the model. BSBR showed higher COD removal efficiencies and greater ability to maintain stability under all cases of operation compared to conventional SBR. Conclusions drawn from simulations were similar to those obtained from the experimental results. At maximum concentrations of influent COD (27,500 mg/L), BSBR maintained its stability and the treated effluent was in the permissible limits. There was a large variation in effluent values of COD in the case of organic and hydraulic shock loads concentrations, however, BSBR showed a faster recovery of its stability compared to SBR. Overall, the results demonstrated that addition of bio-media as a modification of the conventional SBR (BSBR reactor) provided better performance in all investigated conditions for the treatment of pulp and paper wastewater.

References

[1] V. Kumar, P. Dhall, S. Naithani, A. Kumar, R. Kumar, Biological approach for the treatment of pulp and paper industry effluent in sequence batch reactor, J. Biorem. Biodegrad., 5 (2014), doi:10.4172/2155-6199.1000218.

[2] J.-W. Ahn, M. Lim, Characteristics of wastewater from plup and paper industry and its biological treatment technologies., J. Korean Inst. Resour. Recycl., 18 (2009) 16–29.

[3] M. Edalat Manesh, Utilization of Pulp and Paper Mill Sludge as Filler in Nylon Biocomposite Production, University of Toronto, Toronto, 2012.

[4] R. Ranjith Kumar, K. Subramanian, Treatment of Paper and Pulp Mill Effluent using Sequential Batch Reactor, International Conference on Biological, Civil and Environmental Engineering, March 17–18, Dubai (UAE), 2014, pp. 39–42.

[5] F. Kargi, A. Uygur, Nutrient removal performance of a sequencing batch reactor as a function of the sludge age, Enzyme Microb. Technol., 31 (2002) 842–847.

[6] P.G.Patil, G.S. Kulkarni, S.V. Kore, V.S. Kore, Aerobic sequencing batch reactor for wastewater treatment, Int. J. Eng. Res. Technol., 2 (2013) 534–550.

[7] M. Nasr, A. Elreedy, A. Abdel-kader, W. Elbarki, Environmental consideration of dairy wastewater treatment using hybrid sequencing batch reactor, Sustainable Environ. Res., 24 (2014) 449–456.

[8] A.A. Ulson De Souza, J.M. Muneron De Mello, H. Lima Brandão, A. Da Silva, S.M.D.A.G. Ulson De Souza, Application of Biofilm in the Degradation of Contaminants in Industrial Effluents, W.C. Bailey, Ed., Biofilms: Formation, Development and Properties, Nova Science Publishers, Inc., NY, USA, 2011.

[9] A.H. Khan, I. Khan, N.A. Khan, M. Islam, A. Hussain, Reduction of COD of pulp and paper mill effluent using sequencing batch reactor, Int. J. Sci. Eng. Res., 4 (2013) 19–22.

[10] V.K. Verma, R.K. Gupta, J. Rai, Biosorption of Pb and Zn from pulp and paper industry effluent by water hyacinth (*Eichhornia crassipes*), J. Sci. Ind. Res., 64 (2005) 778–781.
[11] M. Henze, L. Grady, W. Gujer, G.V.R. Marais, T. Matsuo, Activated Sludge Model No. l, IAWQ Scientific and Technical Report No. 1, 1986.
[12] M. Henze, W. Gujer, T. Mino, T. Matsuo, M.C. Wentzel, G.V.R. Marais, M.C.M. Van Loosdrecht, Activated sludge model no. 2d, ASM2d, Water Sci. Technol., 39 (1999) 165–182.
[13] W. Gujer, M. Henze, T. Mino, M. Van Loosdrecht, Activated sludge model no. 3, Water Sci. Technol., 39 (1999) 183–193.
[14] M. Henze, C.P.L. Grady, W. Gujer, G.V.R. Marais, T. Matsuo, A general model for single-sludge wastewater treatment systems, Water Res., 21 (1987) 505–515.
[15] S. Sumathi, Y.-T. Hung, Treatment of Pulp and Paper Mill Wastes, L.K. Wang, Y.T. Hung, H.H. Lo, C. Yapijakis, Eds., Waste Treatment in the Process Industries, Taylor & Francis, USA, 2006, pp. 453–497.
[16] N.A. Khan, F. Basheer, D. Singh, I. Farooq, Treatment of paper and pulp mill wastewater by column type sequencing batch reactor, J. Ind. Res. Technol., 1 (2011) 12–16.
[17] P. Battistoni, G. Fava, M.L. Ruello, Heavy metal shock load in activated sludge uptake and toxic effects, Water Res., 27 (1993) 821–827.
[18] B. Thippeswamy, C.K. Shivakumar, M. Krishnappa, Bioaccumulation potential of *Aspergillus niger* and *Aspergillus flavus* for removal of heavy metals from paper mill effluent, J. Environ. Biol., 33 (2012) 1063–1068.
[19] F.W. Gilcreas, Standard Methods for the Examination of Water and Waste Water, American Public Health Association, American Water Works Association, 2008.
[20] N.A. Khan, S.U. Khan, D.T. Islam, S. Ahmed, I.H. Farooqi, M.H. Isa, A. Hussain, F. Changani, A. Dhingra, Performance evaluation of column-SBR in paper and pulp wastewater treatment: optimization and bio-kinetics, Desal. Water Treat., 156 (2019) 204–219.
[21] C.S. Butler, J.P. Boltz, Biofilm Processes and Control in Water and Wastewater Treatment, S. Ahuja, Ed., Comprehensive Water Quality and Purification, Elsevier, USA, 2014, pp. 90–107.
[22] M. Von Sperling, C.A. De Lemos Chernicharo, Biological Wastewater Treatment in Warm Climate Regions, IWA Publishing, London, 2005.
[23] M.N. Cabrera, Pulp Mill Wastewater: Characteristics and Treatment, R. Farooq, Z. Ahmad, Eds., Biological Wastewater Treatment and Resource Recovery, IntechOpen, 2017. Available at: https://www.intechopen.com/books/biological-wastewater-treatment-and-resource-recovery/pulp-mill-wastewater-characteristics-and-treatment
[24] S. Hassan, Utilization of Bio-film Sequencing Batch Reactor for Pulp and Paper Industrial Wastewater Treatment, Alexandria University, Egypt, 2017.