



## Removal Efficiency of Nitrogen, Phosphorus and Heavy Metal by Intermittent Cycle Extended Aeration System from Municipal Wastewater (Yazd-ICEAS)

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### ABSTRACT

**Introduction:** Sequential batch reactor (SBR) is one of the modified biological treatment systems which is able to remove BOD<sub>5</sub>, Nitrogen, and phosphorus from wastewater. The object of this study is to determine the removal efficiency of nitrogen, phosphorus, and heavy metals from municipal wastewater by the advanced SBR system.

**Materials and Methods:** This descriptive-analytical and cross-sectional study was conducted on advanced SBR in Yazd city wastewater treatment plant during a one-year period (from September, 2014 until August, 2015). The samples were collected from the influent and effluent of the advanced SBR as a composite in order to measure BOD<sub>5</sub>, TKN, NH<sub>4</sub><sup>+</sup>, TP parameters, and heavy metals monthly. Also, statistical t-test was used to compare heavy metals quantities with standard ones.

**Results:** The results showed that the mean of removal efficiency of BOD<sub>5</sub>, TKN, NH<sub>4</sub><sup>+</sup>, and TP were 92.24, 80.36, 90.41, and 66.41 percent, respectively. Also, the removal efficiency of Iron (Fe), Plum bum (Pb), Nickel (Ni), Zink (Zn), Chromium (Cr), and Cadmium (Cd) were 47.77 %, 40.71 %, 24.79 %, 12.29 %, 5.70 % and 5.65 %, respectively.

**Conclusion:** The high removal efficiency of BOD<sub>5</sub>, TKN, and NH<sub>4</sub><sup>+</sup> showed that this advanced SBR system had an appropriate efficiency for nitrification. Phosphorus removal (TP) had a lower efficiency than those of NH<sub>4</sub><sup>+</sup> and TKN, but it was within the environmental standard limits. On the other hand, in the advanced SBR the removal efficiency of heavy metals for Cd was not within the standard limits.

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### Introduction

Nowadays, treatment and reuse of domestic wastewater is required for public health maintenance, environmental protection, prevention of water resources contamination, and reuse of treated wastewater in agriculture and industry. This is crucial because of the population increase and water resources shortage<sup>1, 2</sup>. Nitrogen and phosphorus are among the wastewater pollutants,

which can increase eutrophication and decrease water resources' qualities when entering the surface water resources<sup>3, 4</sup>. Heavy metals are the other pollutants which enter the water resources through domestic and industrial wastewaters. They can cause many problems for both health and environment<sup>5</sup>.

Also, along with the increasing growth in biological technology, the physical, chemical, and

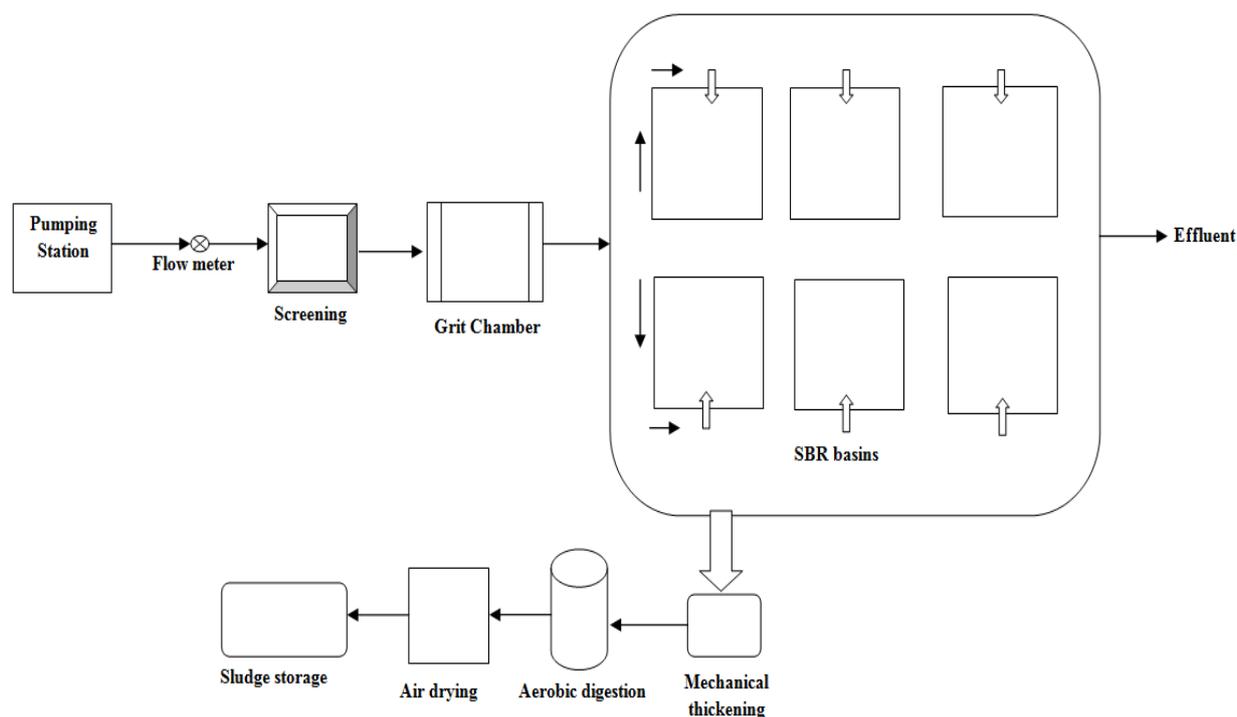
biological treatment systems of wastewater have developed considerably<sup>6</sup>. Among the different processes of wastewater treatment, biological treatment systems are the desirable domestic ones because of their simple and adaptable operation, low operation and maintenance cost, and high efficiency<sup>7-10</sup>. Advanced Sequential Batch Reactor (or advanced SBR) is one of the modified activated sludge biological treatment systems. This reactor is simple and highly adaptable to hydraulic and organic shocks, and is able to remove BOD as well as phosphorous and also do intermittent nitrification and denitrification<sup>11-13</sup>. The difference between advanced SBR process and conventional SBR system is that the raw wastewater flow is continuous in this system while the other stages, consisting of feeding or filling, reaction or aeration, settling, decanting, and idling<sup>14-17</sup> are similar to the conventional SBR. In the advanced SBR, the wastewater was introduced into pre-react zone which is separated from the whole reactor by a parapet. Therefore, the mixed liquid will have more rest in the settlement and discharge stages. Also, because of high F/M ratio in the pre-react zone, the process acts selectively and so prevents filamentous bacteria growth and makes settling process ameliorate. After pre-react zone, the main react zone starts which consists of aeration, settling, and idling<sup>12, 13</sup>. The wastewater enters the basin through the baffle wall pores and after the aeration and the settling processes, the effluent exits from the systems sequentially<sup>18, 19</sup>. The advanced SBR advantage over the conventional SBR process is that this system is fully automatic. Additionally, because the mixed liquid will have more rest in the settlement and discharge stages of SBR process, the efficiency of nitrogen and phosphorus removal increases and this is considered as a nitrogen biological removal process. Also, because it requires one basin, the investment costs decrease considerably in

relation to conventional SBR process<sup>20</sup>. The advanced SBR process is applicable in many countries like China, Ukraine, Peru, Qatar, and United State for replacing with the old stabilization ponds or as a treatment process in the low space regions or in the case of requiring effluents with higher quality<sup>11, 13</sup>. With respect to the high biological removal efficiency of nitrogen and through the advanced SBR, this study aims to determine the removal efficiency of Nitrogen, phosphorus, and heavy metals by the advanced SBR process in municipal wastewater of Yazd city.

### Materials and Methods

This descriptive-analytical and cross-sectional study was conducted on advanced SBR in Yazd city wastewater treatment plant during a one-year period (from September, 2014 until August, 2015). The advanced SBR system of Yazd city was established in 2012 to treat the municipal wastewater; its capacity was 150 and 350 thousand people in the first and final phases, respectively. The average entering flow rate of this treatment plant was 170 liters per second during the study.

In this process, the wastewater was first introduced into the preliminary treatment units consisting of screening and grit removal chambers and then it was discharged into the advanced SBR reactors. Then, in each reactor, the mixed operations with retention time of 0.9 hours and the aeration with 2.4 hours were performed. After the final stages of biological treatment, the sedimentation process has started with one hour retention time and continues until the complete discharge of effluent within a half hour of retention time. All of these stages were performed in one reactor and the total retention time in the whole system was 4.8 hours in each period. Also, the additional sludge was decanted in every operating shift (Figure. 1).



**Figure 1:** Schematic of ICEAS process in Yazd's wastewater treatment plant

The samples were collected from influent and effluent of the process as a mixed method monthly to measure TKN (Total Kjeldahl nitrogen),  $\text{NH}_4^+$ , TP parameters, and heavy metals. In this study, the Kjeldahl Digestion for TKN, the HACH DR 5000 Spectrophotometer for  $\text{NH}_4^+$  and TP, and the Atomic Absorption instrument were used for determination. In order to collect the samples, the special sampling containers were applied, then, the samples were transported to the laboratory in the standard conditions and the mentioned parameters were determined according to "Standard methods for the examination of water and wastewater" book. Finally, after collecting the data, the Excel software was used to provide the charts, tables, and data analysis.

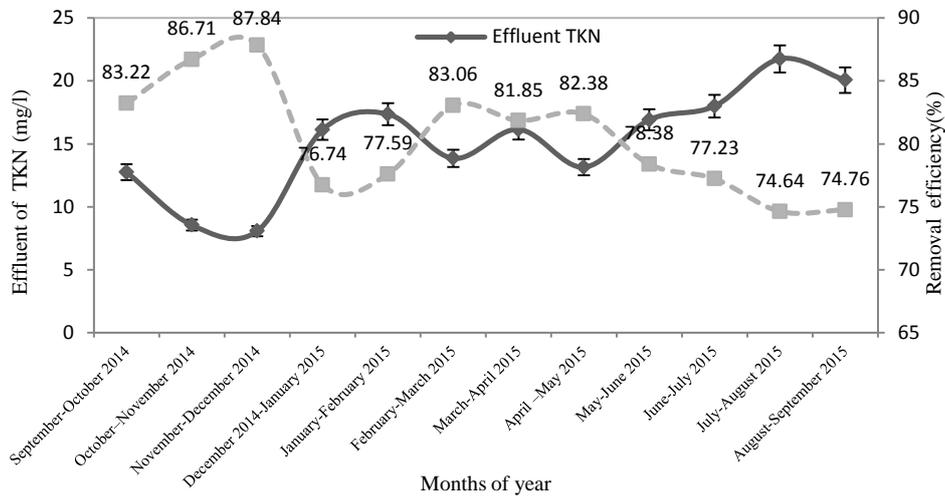
## Results

### *Removal efficiency of TKN and $\text{NH}_4^+$ by the advanced SBR system*

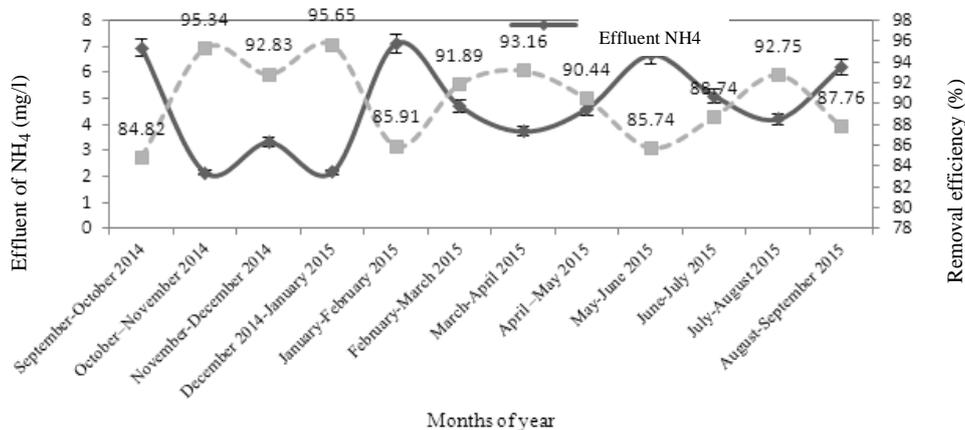
The results showed that the mean  $\pm$  standard deviation of the annual TKN concentrations in the influent and effluent of the advanced SBR were  $76.79 \pm 7.34$  and  $15.22 \pm 4.16$  (mg/l), respectively and those of  $\text{NH}_4^+$  were  $49.95 \pm 4.58$  and  $4.43 \pm 1.73$  mg/l (Table 1). The annually averaged removal efficiencies of TKN and  $\text{NH}_4^+$  were  $80.36 \pm 4.43$  and  $90.41 \pm 3.76$  %, respectively. Also, the results indicated that the output average of  $\text{NH}_4^+$  concentrations in November and January and those of TKN in November and December were lower and the removal efficiencies in these months were higher than those in the other months of the year (Figures 2, 3).

**Table 1:** The Mean and standard deviation of the NH<sub>4</sub><sup>+</sup> and TKN concentrations (mg/l) in the influent and effluent of the advanced SBR

Months of year	Influent		Effluent	
	TKN	NH <sub>4</sub> <sup>+</sup>	TKN	NH <sub>4</sub> <sup>+</sup>
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
September-October 2014	75.98 ± 17.69	45.78 ± 7.77	12.75 ± 1.29	6.95 ± 0.61
October–November 2014	64.32 ± 5.83	46.10 ± 3.78	8.55 ± 1.03	2.15 ± 0.30
November-December 2014	66.42 ± 3.48	46.17 ± 2.83	8.07 ± 1.70	3.31 ± 2.09
December 2014-January 2015	69.33 ± 5.81	49.70 ± 8.01	16.12 ± 2.41	2.16 ± 1.11
January-February 2015	77.48 ± 15.56	50.50 ± 5.29	17.36 ± 1.11	7.12 ± 0.82
February-March 2015	81.73 ± 11.04	57.96 ± 9.23	13.85 ± 1.35	4.71 ± 1.25
March-April 2015	89.01 ± 19.79	54.45 ± 3.88	16.15 ± 0.77	3.72 ± 0.67
April –May 2015	74.62 ± 14.45	48.12 ± 10.88	13.15 ± 2.51	4.60 ± 1.61
May-June 2015	78.25 ± 7.80	46.75 ± 7.51	16.91 ± 1.12	6.66 ± 0.76
June-July 2015	79.06 ± 7.22	45.18 ± 8.84	18.01 ± 2.81	5.08 ± 1.59
July-August 2015	85.75 ± 14.74	57.91 ± 9.38	21.75 ± 13.76	4.20 ± 2.10
August-September 2015	79.50 ± 18.53	50.81 ± 9.53	20.06 ± 2.69	6.21 ± 1.35
Annual mean	76.79 ± 7.34	49.95 ± 4.58	15.22 ± 4.16	4.74 ± 1.73



**Figure 2:** The mean concentrations of TKN in the effluent and the removal efficiency of TKN during the different months of year



**Figure 3:** The mean concentrations of NH<sub>4</sub><sup>+</sup> in the effluent and the removal efficiency of NH<sub>4</sub><sup>+</sup> during the different months of year

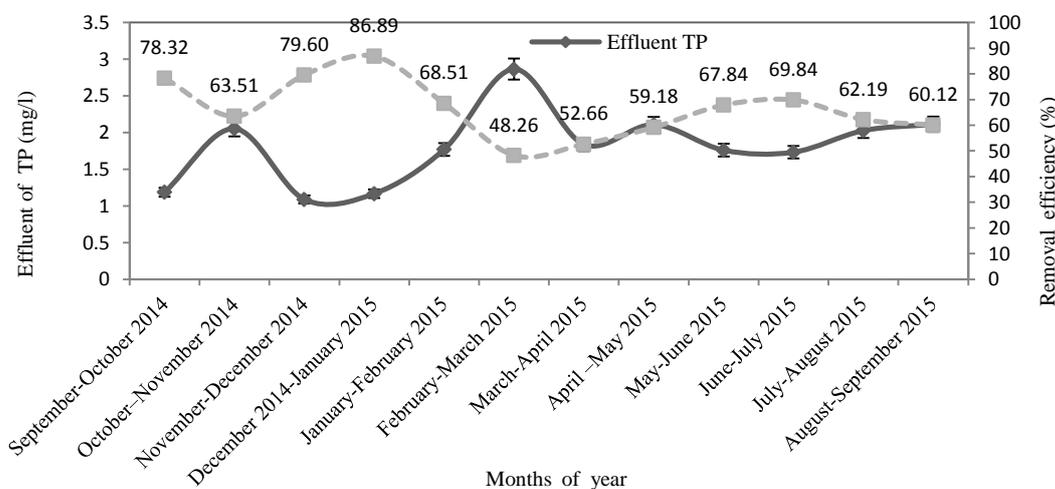
**Removal efficiency of TP by the advanced SBR system**

The mean ± standard deviation of the annual TP concentrations in the influent and effluent of the advanced SBR were 5.61 ± 1.14 and 1.81 ± 0.50 mg/l, respectively. The annually averaged removal

efficiency of TP was 66.41 ± 11%. Also, the results showed that the effluent average of the TP concentrations in December and January were lower and the removal efficiencies in these months were higher than those in the other months of the year (Table 2) (Figure. 4).

**Table 2:** The Mean and standard deviation of the TP concentrations (mg/l) in the influent and effluent of the advanced SBR

Months of year	Influent	Effluent
	Mean ± SD	Mean ± SD
September-October 2014	5.47 ± 0.92	1.18 ± 0.41
October–November 2014	5.62 ± 0.25	2.05 ± 0.94
November-December 2014	5.34 ± 0.44	1.09 ± 0.70
December 2014-January 2015	8.90 ± 7.34	1.16 ± 0.44
January-February 2015	5.62 ± 0.35	1.77 ± 0.39
February-March 2015	5.53 ± 0.35	2.86 ± 0.55
March-April 2015	3.88 ± 2.89	1.84 ± 1.41
April –May 2015	5.16 ± 0.35	2.10 ± 0.23
May-June 2015	5.47 ± 0.12	1.76 ± 0.71
June-July 2015	5.74 ± 0.47	1.73 ± 0.49
July-August 2015	5.36 ± 0.24	2.02 ± 0.95
August-September 2015	5.29 ± 0.58	2.11 ± 0.68
Annual mean	5.61 ± 1.14	1.81 ± 0.50



**Figure 4:** The mean concentrations of TP in the effluent and the removal efficiency of TP during the different months of year

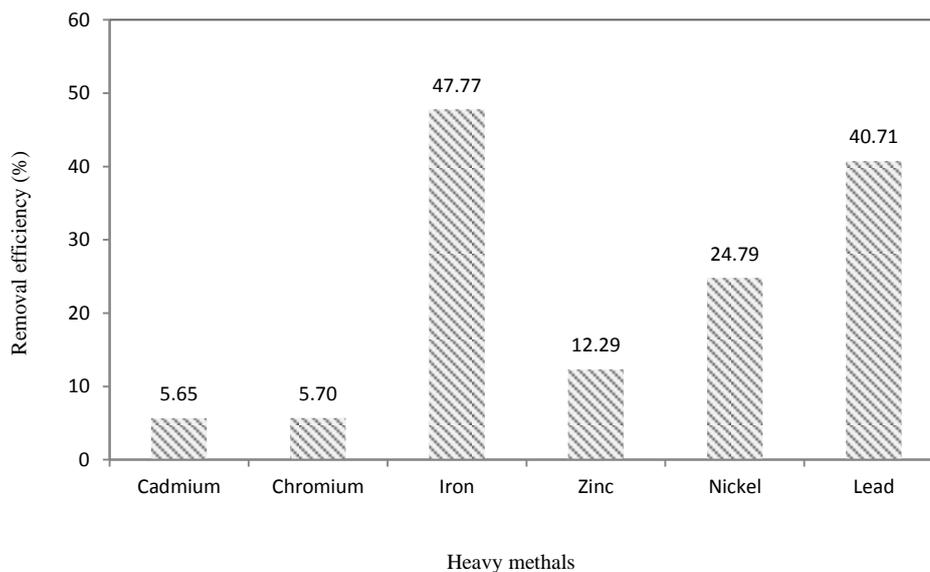
**Removal efficiency of heavy metals by the advanced SBR system**

The results represented that the mean removal efficiencies of heavy metals were 47.77 % (Fe), 40.71 % (Pb), 24.79 % (Ni), 12.29 % (Zn), 5.70 %

(Cr), and 5.65 % (Cd), respectively (Figure. 5), (Table. 3).

**Table 3:** The Mean and standard deviation of the heavy metal concentrations (mg/l) in the advanced SBR

Heavy metals	Influent	Effluent
	Mean $\pm$ SD	Mean $\pm$ SD
Cadmium	0.06 $\pm$ 0.04	0.06 $\pm$ 0.04
Chromium	0.11 $\pm$ 0.1	0.1 $\pm$ 0.1
Iron	0.74 $\pm$ 0.89	0.39 $\pm$ 0.61
Zinc	0.14 $\pm$ 0.17	0.12 $\pm$ 0.13
Nickel	0.39 $\pm$ 0.41	0.19 $\pm$ 0.33
Lead	0.21 $\pm$ 0.24	0.13 $\pm$ 0.1

**Figure 5:** Removal efficiency of heavy metals by the advanced SBR system

## Discussion

### Removal of TKN and $\text{NH}_4^+$

In this study, the removal efficiencies of TKN and  $\text{NH}_4^+$  were  $80.36 \pm 4.43$  and  $90.41 \pm 3.76$  %, respectively. Further, they were higher in November and December than those in the other months of the year. TKN is the sum of organic nitrogen and ammonium ( $\text{NH}_4^+$ ). Gradually, the amounts of the TKN (organic and ammoniacal nitrogen) decreased and those of nitrate increased in the nitrification of wastewater treatment. Thus, further the removal efficiency of TKN, the better is the nitrification performance. The optimum temperature of microorganism responsible for nitrification process is  $30^\circ\text{C}$ <sup>21, 22</sup>. Because the weather temperature in Yazd decreases from October to December and thus, the temperature of the advanced SBR falls in the

mentioned range, the removal efficiencies of TKN and  $\text{NH}_4^+$  are more than those of the other months of the year. Because the weather temperature reaches to  $40^\circ\text{C}$  in the summer and it gets cold in winter, the optimum temperature of nitrification and as a result the removal of TKN and  $\text{NH}_4^+$  were not provided. Moreover, because the nitrification process performance depends on the BOD/TKN ratio and this ratio is better to be less than or equal to 3, it can be seen that either the loading of input  $\text{BOD}_5$  is lower or that of TKN is higher. Consequently, the nitrification process is performed in a better condition and the removal efficiency of TKN and  $\text{NH}_4^+$  are also increased<sup>21, 23, 24</sup>.

### Removal of Total Phosphorus

In this study, the mean removal efficiency of TP was  $66.41 \pm 11.24$  % and the removal

efficiencies were higher in December and January than those of the other months of the year. Zeinaddine et al, showed that the removal efficiency of phosphorus by advanced SBR was 59.5% in average, the hydraulic input loading increased, and the removal efficiency decreased. Therefore, it can be seen that the hydraulic input loadings in December and January were less than those of the other months of the year and had an effect on the removal efficiency of phosphorus<sup>25</sup>. Generally, the removal efficiency of phosphorus by advanced SBR was less than those of TKN and  $\text{NH}_4^+$ . The removal of phosphorus requires anaerobic and aerobic conditions subsequently, thus, the phosphorus is discharged in the anaerobic condition and is consumed in the aerobic condition. Because the advanced SBR is an aerobic process, we require an anaerobic condition to increase the removal of phosphorus<sup>13, 21, 26, 27</sup>.

#### Removal of heavy metals

In this study, the removal efficiency of heavy metals for Iron (Fe), Plum bum (Pb), Nickel (Ni), Zink (Zn), Chromium (Cr), and Cadmium (Cd) were 47.77 %, 40.71 %, 24.79 %, 12.29 %, 5.70 % and 5.65 %, respectively. Pagnanelli and his colleagues surveyed the removal efficiency of heavy metals by SBR system and the results showed that the effluents of Cd and Pb were 0.45 and 0.07 mg/l, respectively<sup>28</sup>. The results also indicated that the main mechanism of heavy metals' removal from wastewater is biological absorption on biomass surface plus physical-chemical mechanism<sup>29, 30</sup>. The Pb metal is precipitated at pH 7.5 as a hydroxide even in a very low concentration<sup>31</sup>. So, with respect to the pH of wastewater in this study (7-7.5), it can be seen that the removal efficiency of Pb is higher than those of the other metals. Indeed, increasing the retention time of sludge or adding the biological sludge can be used to increase the removal efficiency of the other metals<sup>32</sup>. The previously conducted studies stated that the removal efficiencies of heavy metals can be increased by using adsorption

process and applying adsorbents particularly low-cost (such as activated carbon and tree bark) and biological (such as algal and bacterial biomass, skin of crab, etc) ones.<sup>32, 33</sup>

#### Conclusion

The high removal efficiencies of TKN and  $\text{NH}_4^+$  showed that this process is appropriate for performing nitrification. Indeed, in this condition the amount of nitrate is increased in effluent and an anaerobic condition is required for the removal of nitrate. The removal efficiency of phosphorus (TP) is less than that of TKN and  $\text{NH}_4^+$  by advanced SBR process. Because the removal of phosphorus requires anaerobic and aerobic conditions subsequently and the advanced SBR process is an aerobic process, we require anaerobic condition to increase the removal of phosphorus. The removal efficiencies of heavy metals by the advanced SBR showed that this system is not appropriate for the removal of Cd within the standard limit.

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#### Conflict of interest

We have no competing interests.

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#### References

1. Zazouli MA, Ghahramani E, Ghorbanian AlahAbad M, et al. Survey of activated sludge process performance in treatment of agghala industrial town wastewater

- in Golestan province in 2007. *Iran J Health Environ.* 2010; 3(1): 59-66.
2. Shahi DH, Eslami H, Ehrampoosh MH, et al. Comparing the efficiency of *Cyperus alternifolius* and *Phragmites australis* in municipal wastewater treatment by subsurface constructed wetland. *Pak J Biol Sci.* 2013; 16(8): 379.
  3. Panswad T, Dounghchai A, Anotai J. Temperature effect on microbial community of enhanced biological phosphorus removal system. *Water Res.* 2003; 37(2): 409-15.
  4. Loganathan BG, Sajwan KS, Sinclair E, et al. Perfluoroalkyl sulfonates and perfluorocarboxylates in two wastewater treatment facilities in Kentucky and Georgia. *Water Res.* 2007; 41(20): 4611-20.
  5. Sekomo CB, Rousseau DP, Saleh SA, et al. Heavy metal removal in duckweed and algae ponds as a polishing step for textile wastewater treatment. *Ecol Eng.* 2012;44:102-10.
  6. Sonune A, Ghate R. Developments in wastewater treatment methods. *Desalination.* 2004; 167: 55-63.
  7. Fernandes H, Jungles MK, Hoffmann H, et al. Full-scale sequencing batch reactor (SBR) for domestic wastewater: performance and diversity of microbial communities. *Bioresour technol.* 2013;132:262-8.
  8. Mohan SV, Rao NC, Prasad KK, et al. Treatment of complex chemical wastewater in a sequencing batch reactor (SBR) with an aerobic suspended growth configuration. *Process Biochem.* 2005; 40(5): 1501-8.
  9. Sathian S, Rajasimman M, Radha G, et al. Performance of SBR for the treatment of textile dye wastewater: Optimization and kinetic studies. *Alexandria Eng J.* 2014; 53(2): 417-26.
  10. Zeng W, Yang Y, Li L, et al. Effect of nitrite from nitrification on biological phosphorus removal in a sequencing batch reactor treating domestic wastewater. *Bioresour technol.* 2011; 102(12): 6657-64.
  11. Dutta A, Sarkar S. Sequencing batch reactor for wastewater treatment: recent advances. *current pollut rep.* 2015; 1(3): 177-90.
  12. Eslami H, Hematabadi PT, Ghelmani SV, et al. The performance of advanced sequencing batch reactor in wastewater treatment plant to remove organic materials and linear alkyl benzene sulfonates. *Jundishapur Journal of Health Sciences.* 2015; 7(3): 33-9.
  13. Metcalf E, Eddy H. *Wastewater engineering: treatment and reuse.* New York: McGraw-Hill; 2003.
  14. Pazoki M, Takdastan A, Jaafarzadeh N. Investigation of minimization of excess sludge production in sequencing batch reactor by heating some sludge. *Asian J Chem.* 2010; 22(3): 1751.
  15. Takdastan A, Mehrdadi N, Torabian A, et al. Investigation of excess biological sludge reduction in sequencing batch reactor. *Asian J Chem.* 2009; 21(3): 2419.
  16. Ganigué R, Volcke EIP, Puig S, et al. Impact of influent characteristics on a partial nitrification SBR treating high nitrogen loaded wastewater. *Bioresour technol.* 2012;111:62-9.
  17. Amin MM, Hashemi H, Bina B, et al. Complementary treatment of leachate using sequencing batch reactor. *International Journal of Health System and Disaster Management.* 2014; 2(4): 216.
  18. Bicudo J, Svoboda IF. Effects of intermittent-cycle extended-aeration treatment on the fate of nutrients, metals and bacterial indicators in pigslurry. *Bioresour technol.* 1995; 54(1): 63-72.
  19. Bo L, Yun-hong L. Application of ICEAS in the 4th wastewater treatment plant in Kunming city. *Water Wastewater Engin.* 2006;3:11-5.
  20. Zhang Z, Zhou F. Domestic sewage treatment by modified ICEAS under low temperature condition. *Technol Water Treatment.* 2007; 33(4): 56.
  21. Bitton G. *Wastewater microbiology:* Hoboken, New Jersey :John Wiley & Sons; 2005.
  22. Ge S, Peng Y, Qiu S, et al. Complete nitrogen removal from municipal wastewater via partial nitrification by appropriately alternating anoxic/aerobic conditions in a continuous plug-

- flow step feed process. *Water Res.* 2014; 55: 95-105.
23. Jing S-R, Lin Y-F. Seasonal effect on ammonia nitrogen removal by constructed wetlands treating polluted riverwater in southern Taiwan. *Environ Pollut.* 2004; 127(2): 291-301.
  24. Reid JH, inventor. Anaerobic lagoon or tank design for effluent carbon to nitrogen ratio control. United States patent US 9, 005, 442. 2015.
  25. Zeinaddine HR, Ebrahimi A, Alipour V, et al. Removal of nitrogen and phosphorous from wastewater of seafood market by intermittent cycle extended aeration system (ICEAS). *J health sci surveil sys.* 2013; 1(2): 89-93.
  26. Ahn KH, Song KG, Choa E, et al. Enhanced biological phosphorus and nitrogen removal using a sequencing anoxic/anaerobic membrane bioreactor (SAM) process. *Desalination.* 2003; 157(1): 345-52.
  27. Amini M. Phosphorus removal from dairy wastewater in batch systems under simultaneous aerobic/anaerobic conditions: application of response surface methodology. *Int J Engintrans c: Aspects.* 2015; 28(6): 855.
  28. Pagnanelli F, Mainelli S, Bornoroni L, et al. Mechanisms of heavy-metal removal by activated sludge. *Chemosphere.* 2009; 75(8): 1028-34.
  29. Hu Z, Chandran K, Grasso D, et al. Impact of metal sorption and internalization on nitrification inhibition. *Environ sci technol.* 2003; 37(4): 728-34.
  30. Kornaros M, Lyberatos G. Biological treatment of wastewaters from a dye manufacturing company using a trickling filter. *J Hazard Mater.* 2006; 136(1): 95-102.
  31. Liu Q, Liu Y. Distribution of Pb (II) species in aqueous solutions. *J colloid interface sci.* 2003; 268(1): 266-9.
  32. Sirianuntapiboon S, Hongrisuwan T. Removal of Zn<sup>2+</sup> and Cu<sup>2+</sup> by a sequencing batch reactor (SBR) system. *Bioresour technol.* 2007; 98(4): 808-18.
  33. Fu F, Wang Q. Removal of heavy metal ions from wastewaters: a review. *J Environ Manag.* 2011; 92(3): 407-18.